Competition and strategic behavior in energy markets

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Remco van Eijkel

Contents

Chapter 1

Introduction

This thesis deals with various aspects of market behavior in deregulated energy markets. In the last thirty years, the energy sector has been among those industries that have undergone a worldwide deregulation process with the aim to enhance overall market performance. This process started in the Anglo-Saxon world under the Thatcher government in the U.K. and the Carter and Reagan regimes in the U.S. and, often using the U.K. and U.S. liberalization policies as blueprints, many countries followed suit. Next to the energy sector, other industries that have been privatized include transportation, postal services, health care and telecommunications (see e.g. Armstrong and Sappington, 2006).

Economic theory has proved to be a useful guidance in developing reform policies that create well-functioning markets.[1] First of all, the theory of *incentive regulation* delivers valuable tools if natural monopolies in one or more market segments remain. This is particularly true for most of the sectors that have been liberalized, as these industries exhibit significant economies of scale in the provision of infrastructure services. This makes it socially undesirable to duplicate physical networks and as a result, a monopolistic firm, under control of a regulator, owns the infrastructure assets. Insights from the research on incentive regulation can be applied by the regulator to entice the monopolistic network owner to improve upon its own performance and, given the monopolist's pivotal position in the industry, to ameliorate the func-

[1]Numerous studies in this area have not only aimed at characterizing the main determinants of successful deregulation, but have also attempted to predict the qualitative and quantitative effects of restructuring industries. Winston (1993), providing an interesting overview of research on various U.S. sectors that have been liberalized, assesses that economists' predictions about the effects of deregulation are by and large accurate.

tioning of other layers of the value chain at the same time. This theory recognizes that the regulated firm has an informational advantage over the regulator, which implies that the optimal regulatory policy leaves some rent to the firm in order to bring the firm's incentives more in line with the regulator's objective.[2]

In parts of the industries where markets have been created, like wholesale and retail segments, research in the field of *industrial organization* (IO) provides us with useful insights into optimal market design. Focusing on strategic behavior of firms in imperfectly competitive markets, IO models seem very suitable to study competitive issues in energy markets as there is ample empirical support that suppliers on these markets are able to manipulate prices (see e.g. Wolfram, 1999; Borenstein and Bushnell, 1999; Borenstein, Bushnell and Wolak, 2002).[3]

Although economic theory provides useful tools that can be used to restructure industries, turning regulated sectors into well-functioning markets where competitive forces prevail is far from trivial. It has been demonstrated that energy industries are among the most challenging ones to liberalize. This is not only caused by the institutional complexities surrounding these industries, but also by the fact that these sectors have been subject to substantial alterations along other dimensions. A main driver of these changes has been the growing concern about the environment. Due to the widespread consensus that the level of pollution caused by the energy sector should be reduced, markets for emission rights have been created. These emission rights put a cap on the level of a pollutant (e.g. greenhouse gases) that can be emitted. It is well-known that poorly designed markets for emission rights not only provide firms insufficient incentives to produce in a more environmentally friendly way, but also have a negative effect on the efficiency at the deregulated parts of the industries (see Newbery, 2008).[4] Furthermore, environmental concerns and the recognition that the reserves of fossil fuels like oil, coal and natural gas are depleted at a rather fast rate have led to the development of renewable energy sources, like solar power and biomass. In 2007, the share of renewables in world electricity production was 18 percent and this fraction is expected to grow to 23 percent in 2035 (EIA, 2010).

[2]We refer to Laffont and Tirole (1993) and Armstrong and Sappington (2007) for exhaustive discussions on the complexities of designing regulatory policy when a monopoly seller is better informed than the regulator about demand conditions or the cost of production.

[3]In addition, in a recent report the European Commission (EC, 2007) states that consumers cannot reap the full benefits of the recent EU-energy market liberalization because suppliers still have substantial power to manipulate market outcomes.

[4]See also Stavins (2003) for an extensive analysis of the various market-based policy instruments that have been implemented worldwide to restrict pollution.

Against this background, policy makers face the challenge to implement effective deregulation policies that bring about more competition and therefore lead to a higher market efficiency. This is important, since the availability of relatively cheap and reliable sources of energy is crucial for the performance of the economy as a whole. Energy sources are not only indispensable for households as they are utilized for heating, cooking and lighting purposes, but also for various industries where energy commodities are an essential input in the production process. For instance, natural gas is used by residential consumers to heat their houses but is also deployed in the production of electricity and ammonia.

This thesis contributes to a better understanding of market behavior in restructured energy industries, which ultimately could help in developing more adequate policy measures. Throughout the thesis, we will mainly focus on those parts of the value chain that have been opened up to competition. Since we are to believe that suppliers in these segments have considerable market power, as is mentioned above, our research primarily pertains to the domain of IO. Our analysis provides theoretical insights as well as empirical evidence on the strategic interactions between participants in energy markets.

Even though most of the research discussed in the following chapters applies to energy markets in general, our main focus will be on the wholesale market for natural gas. A first explanation for this choice is that most studies on deregulated energy industries deal with electricity markets, while gas markets have not received much attention in the literature so far. Admittedly, gas and power markets have a lot of common characteristics which may make it tempting to carry over insights gained about the electricity sector directly to the gas industry. While this may be true for many aspects, one should be aware of the way in which institutional dissimilarities between the two sectors call for different forms of market design. In Chapter 2 of this thesis, we will see that this is particularly true when it comes to the provision of transportation services and the pricing of it. Another reason for why we mainly concentrate on natural gas markets has a more pragmatic nature: we were able to collect a rather rich data set for this industry that provides us information about the number of active firms, the level of trade in spot and forward contracts and the amounts transacted over-the-counter and on centralized exchanges. These data will be used in Chapter 4, which is the only empirical study in this thesis.

Similar to most other regulated network sectors, natural gas industries used to be vertically integrated monopolies, state-owned or not, operating under regulatory constraints. These integrated firms possessed exclusive rights to buy from upstream producers at regulated wellhead prices and sell to industrial users like power plants, to final users directly, or to local distribution companies (LDCs), who then in turn sold the gas to final consumers. When it gradually came to the surface that these monopolists were performing rather poorly in efficiency terms, the call for market deregulation grew louder. Some thirty years ago, the passage of the *Natural Gas Policy Act* in the U.S. and the *Gas Act* in the U.K. initiated the worldwide deregulation of gas markets with the main objective to let consumers reap the benefits from intensified competition in the market.

In the European Union, the liberalization started back in the early 1990s, but gained full momentum with the *First Gas Directive*. This ruling abolished import monopolies, forced the opening of markets and imposed the accounting unbundling of vertically integrated network companies. The deregulation of EU gas markets was furthered by the implementation of the *Second Gas Directive*, which required full market opening, regulated third party network access, regulated or negotiated access to storage and ownership unbundling of integrated companies. The Second Directive also required the creation of national energy regulators. Their main roles include the approval of transmission and distribution tariffs, ensuring entrants have access to the transmission networks and making sure the unbundling process is complete. The underlying objective of these measures is to ensure that all customers are able to freely choose among a significant number of gas suppliers.

Although the exact restructuring of markets differs from one country to another, virtually all deregulation policies implemented throughout the world share the same global structures. In the remainder of the Introduction, we will discuss in more detail the main policy actions that have characterized the liberalization of energy industries in general and natural gas markets in particular and explain how our research fits in the context of the restructuring of energy markets.

Separation of transportation and wholesale supply

Usually, one of the first steps taken in order to deregulate natural gas markets is to separate the provision of transportation services from merchant activities. That is, the firm that owns the transport infrastructure is not allowed to be active in gas trading any longer. Historically, in each geographical zone there was a vertically integrated monopolist in place who not only owned the transmission infrastructure but also had exclusive rights to buy from local and foreign producers and in turn to sell directly to consumers or to downstream distribution monopolies and industrial users. In order to limit the monopoly rents the price the network firm could charge to its costumers was regulated and usually linked to the oil price, while there also existed a cap on the profit the vertically integrated monopolist was allowed to earn. Due to this regulatory framework and a lack of competitive pressures, the incentives to reduce cost and to invest in infrastructure were rather weak.

By separating transportation services from trading activities, legislators have aimed to reduce market inefficiencies. Once the network company is no longer allowed to engage in trading activities, there is potentially scope for new firms to enter at the wholesale and retail level.[5] While these segments have been opened up to competition, the provision of transportation services remains to be regulated. The role of the network company, which in deregulated markets is usually called *transmission system operator* (TSO), has changed quite dramatically due to the reform policies. Whereas in the past the transport operator was mainly concerned with buying from upstream producers and in turn shipping and reselling the commodity to public utilities and industrial consumers, in restructured markets the business model of the transport operator mainly consists of allocating and pricing transport capacity, investing in new infrastructure, maintaining the existing network and balancing the transport system.

Clearly, the performance of the TSO has a decisive impact on overall market efficiency. For instance, since transport capacity is an essential input for wholesale firms, the extent to which suppliers have access to pipelines or power networks relates to the scope of energy market competitiveness. Transport capacity and access prices are thus two valuable instruments available to operators to enhance competition in energy markets. Since the TSO's optimal choices regarding investments in infrastructure and the allocation and pricing of it are usually not aligned with what is best for society as a whole, the regulator is assigned the task to entice the transport operator to conduct business in a way that benefits final users of the energy source. Especially when network users have market power on the wholesale market, or when the transport operator still owns (or hold close ties to) a trading arm, or when the operator enjoys a information advantage over the regulator, finding the optimal regulatory framework is not a sinecure. Our research on the optimal regulation of a natural gas TSO, documented in Chapter 2, focuses on the problem of finding the optimal access pricing regime in case users of the network compete with

[5] The European Commission has however raised the concern that there are still significant barriers to enter European energy wholesale markets. Among the most important reasons for the existence of entry barriers are inadequate unbundling of network operators, insufficient opportunities for cross-border trade and a lack of transparency in various market operations (see EC, 2007).

each other in an oligopolistic wholesale market.

The pricing and allocation of transmission rights affect the degree of competition in wholesale markets in various ways.[6] For instance, since network capacity is an essential input for wholesale firms, the supply cost at the wholesale level is directly related to the pricing for access to the transmission network. High access prices may therefore lead to a lower supply in the wholesale market.

Regarding current natural gas markets, another important feature is that pipelines are frequently congested. Especially cross-border trade is hampered by a lack of available transit capacity, which implies that wholesale gas markets remain national in scope. Even in regions where pipeline capacity is relatively large, transmission rights are typically allocated to incumbents under contracts with long duration.[7] This *contractual* congestion reduces the possibilities for entrants to ensure access to pipelines and therefore the opportunity to compete with incumbents. One way to alleviate the problem of contractual congestion is to apply the so-called *use-it-or-lose-it* principle, which means that contracted but unused transport capacity become available on a secondary market. Another solution that has been proposed is to deploy a different mechanism to allocate pipeline capacity. Instead of granting transmission rights based on a first-come, first-served rule, transmission rights could for instance be auctioned.[8] An interesting way to alleviate *physical* congestion is the adoption of the netting mechanism. With netting, the TSO makes use of the fact that flows in reverse direction cancel out. This implies that the pipeline size only has to be large enough to accommodate the net flow, which is the difference between the contracted capacity in one direction and the contracted capacity in the opposite

[6] Joskow and Tirole (2000) study the effects of two different mechanisms to allocate transmission capacity in imperfectly competitive power markets. One mechanism relies on centralized pools where market participants can submit bids to buy or sell electricity. Based on these bids, the network operator decides which bidders are allowed to take or deliver electricity, taking into account the capacity constraint and the physical laws that govern power flows. The system operator may issue financial rights to buyers and generators to compensate them for price differences across nodes that occur in case of network congestion. Another method decentralizes the allocation of transmission by creating a market for physical rights. Under such an approach, electricity generators must hold physical rights to get their supplies dispatched by the operator.

[7] The incumbent suppliers at the wholesale level used to be the trading arms of the integrated monopolies. In some countries, these incumbents are still affiliated to the network company.

[8] In few natural gas markets around the world, auctions have been introduced to allocate network capacity. For instance, in 1999 the British network operator Transco introduced an auction for allocation of transport capacity (McDaniel and Neuhoff, 2004). In electricity, auctioning transmission rights is more common than in gas markets. See e.g. Gilbert, Neuhoff and Newbery (2004) and Fabra, von der Fehr and Harbord (2008) for work on how auction design impacts competition and therefore prices in oligopolistic power markets.

direction.[9]

In the next chapter, we study the optimal regulated tariffs for gas transportation. Allowing for the use of netting, we explicitly distinguish between congested and non-congested pipelines.[10] Considering oligopolistic wholesalers using the pipeline network to serve their costumers, it is shown that regulated tariffs should not only be based on the particular cost structure of the TSO but should also mitigate the social loss from oligopoly. In case of congestion, the highest level of welfare is attained when the counterflow (backhaul) is subsidized while the dominant flow is taxed. The idea is that by subsidizing the counterflow, more backhaul gas is put in the pipeline system which alleviates network congestion and therefore leads to more supply at each entry/exit point in the network. This implies that the optimal tariff structure diverges from access pricing rules that only allow for cost recovery of the TSO. Furthermore, due to the fact that the gas industry differs from electricity sector with respect to the flow physics, the concept of nodal pricing, usually applied to price power transmission, is not optimal when charging the flow of natural gas. [11]

We thus show that implementing sound regulatory rules on the TSO is key in creating well-functioning wholesale markets. While in Chapter 2 we assume that the operator is fully unbundled, finding the optimal regulatory framework becomes an even more difficult task when there still exist close ties between the network operator and a wholesale supplier. In this respect, it is important to note that in many countries the unbundling of the network firms is in a transition phase and that there still exist suppliers which are affiliated to the transport operator. The European Commission has raised the concern that the investment and allocation choices of integrated transport operators are partly driven by the interests of the affiliates. For instance, operators can foreclose access to transmission capacity for rival wholesalers. The literature on vertical foreclosure (see e.g. Katz, 1989; Ordover, Saloner and Salop, 1990; Rey and Tirole, 2007) tells us that the owner of an essential facility can foreclose downstream competitors in various ways, ranging from simply denying the use of the essential input to exercising price discrimination. Energy regulators have tried to fight this anti-competitive behavior by third-party access rules and

[9] Höffler and Wittman (2007) provide a discussion on the application of netting in electricity markets.

[10] There is little further work on transportation pricing in the natural gas industry. Attention has mainly been given to optimal prices under different demand and cost structures in perfectly competitive markets (Cremer and Laffont, 2002; Cremer, Gasmi and Laffont, 2003).

[11] We will elaborate more on the differences between the optimal pricing of gas and electricity transmission in the next chapter.

forbidding the operator to charge discriminatory access prices.[12] Our research on optimal transport tariffs shows that obliging the TSO to set uniform transmission tariffs may not always be beneficial for welfare. Indeed, regulators should forbid transport operators to price discriminate on the basis of the *identity* of network users. However, price discriminating between firms that have different *incentives* aids to social welfare if it weakens the incentives to keep supply artificially low. For instance, in our model one of the wholesale suppliers has an incentive to congest the line, which calls for a discriminatory tariff structure where the dominant (backhaul) flow is taxed (subsidized).[13]

Another complication that a regulator usually faces is that she has an information disadvantage *vis-à-vis* the regulated firm. For example, the company that is regulated knows better its own operating cost than the regulator does. Due to this informational asymmetry, the regulator faces an adverse selection problem as well as moral hazard on the monopolist's side. The reason for being confronted with an adverse selection problem is that the regulator, not knowing the firm's cost, is uncertain about the access price at which the transport operator can recover its cost and thus wants to stay in business. Obviously, the monopolist has an incentive to misreport its true costs to the regulator (Baron and Besanko, 1984). One way to overcome this particular information disadvantage is to set regulated prices that make up for the firm's actual cost *ex post*. Since the *ex post* cost can usually be audited, the incentive for the firm to hide its true cost will be destroyed in this way. However, as this cost-plus or rate-of-return type of regulation fully compensates the regulated firm for the cost it bears there is little incentive to improve on efficiency. This moral hazard on the firm's side further complicates the quest for the optimal regulatory policy.[14]

Luckily, the literature on incentive regulation proves to be a useful guidance for the regulator (see e.g. Baron and Myerson, 1982; Laffont and Tirole, 2000). Probably the most valuable insight from the work on incentive regulation is that a

[12]Third-party access rules force the operator to grant access to their network to non-affiliated firms.

[13]We refer to Laffont and Tirole (1994) and Armstrong, Doyle and Vickers (1996) for further work on optimal access pricing in network industries. The main focus in these papers is on situations where a vertically integrated firm controls an essential input. Vogelsang (2003) presents a review of the research conducted on access pricing in telecommunications.

[14]This moral hazard problem relates to the well-known Averch-Johnson effect. Rate of return regulation dictates that a firm's profit is restricted by a maximum rate of return on the firm's tangible assets, which creates an incentive for regulated companies to overinvest (Averch and Johnson, 1962).

regulated monopolist should be offered a menu of contracts that leads to an incentive-compatible outcome: if the regulated firm is efficient, it chooses a high-powered incentive scheme and if it is less efficient, it chooses a lower-powered incentive scheme. Though in our chapter on optimal regulation we abstract away from asymmetric information issues, we recognize the importance of research in this field. In fact, introducing an information advantage at the operator's side in the framework set out in the next chapter is an interesting starting point for further research.

Long-term commitment versus spot markets

As mentioned above, the regulated monopolies used to hold sole rights to buy from upstream producers and to sell to downstream utilities and industrial users. The conditions of trade in these long-lasting relationships were usually laid down in so-called *take-or-pay* contracts, which typically had a duration of 20 years or more (see e.g. Masten and Crocker, 1985; Hubbard and Weiner, 1986). This type of contract stipulates the per-period minimum amount of gas for which the buyer has to pay, even if this amount is not taken. While the purchaser thus fully bears the quantity risk, the seller is exposed to the price risk since the contract price is usually indexed to the oil price. This indexation protects the buyer against gas prices being higher than prices of competing fuels. In order to create more competition on both wholesale and retail markets, one of the ultimate goals of the unbundling of network companies is to shift trade from long-term bilateral contracts to short-term spot markets.

Examples of spot commodity markets that have been introduced in the electricity industry are the *Pool* in the U.K., ISO in California, the real-time PJM market in Pennsylvania, New Jersey and Maryland, ERCOT in Texas, EPEXSPOT in Austria, France, Germany and Switzerland. In the natural gas sector, we have seen the emergence of trading hubs where market parties can transact gas on a short-term basis. Examples of these gas hubs are NBP in the U.K., the Henry Hub in the U.S., the Zeebrugge Hub in Belgium and TTF in The Netherlands.[15] The 2000-2001 electricity crisis in California has revealed that the combined prevalence of price risks and market power in energy markets may have fatal consequences when risk-hedging mechanisms are absent (Borenstein, 2002; Bushnell, 2004). As a

[15] One development in natural gas has been the creation of virtual hubs, for example the NBP and TTF, as opposed to the more traditional physical hubs, like the Henry Hub and the Zeebrugge Hub. A physical hub is a location where several pipelines come together, so that total physical throughput is delivered at this point. By contrast, virtual hubs contain several entry and exit points that are interconnected, which implies that not all the gas traded has to flow through a single point in the pipeline system.

consequence, in nowadays restructuring, it is widely held that spot markets must necessarily be complemented with forward markets (Ausubel and Cramton, 2009). In an attempt to aid firms to contract forward, in some markets we have witnessed the creation of futures exchanges. Examples of markets for electricity futures are CALPX in California and EEX Power Derivatives in Austria, France, Germany and Switzerland; ENDEX runs a market for natural gas futures in The Netherlands, as well as markets for U.K. and Dutch electricity futures.

The general idea is that well-functioning spot markets allocate scarce resources more efficiently than bilateral negotiations because traders on a liquid spot market are better able to exploit arbitrage opportunities, thereby bringing trade more in line with changes in supply and demand. In addition, long-lasting relationships between buyers and sellers can potentially exert an entry-deterrence effect, as is shown by Aghion and Bolton (1987). The argument is that when incumbents have locked in buyers by means of long-term contracts, the residual demand on the market is relatively small. Potential entrants, not being able to attract sufficiently many downstream costumers, do not find an opportunity to profitably enter the market. Simpson and Wickelgren (2007) show that the entry-deterrence effect of long-term contracts carries over to situations where buyers are downstream competitors instead of final users.[16] The basic intuition behind this result is that the contracts become renegotiation-proof, since downstream firms pass on all benefits from breaching the contract to final consumers while they are still charged the expectation damages.

Ultimately, the question becomes whether moving away from forward-based transactions, either being conducted through bilateral contracts or taking place on centralized futures exchanges, towards trade on a spot market is socially desirable. The literature on forward contracting tells us that answering this question is not straightforward, since trading forward has the potential to deliver social benefits on several accounts. First, as has already been pointed out, forward contracts provide buyers and sellers with an opportunity to hedge against price shocks in the spot market. Without this possibility, the California crisis has demonstrated that firms, being fully exposed to spot price volatility, run a serious risk of getting into financial distress when a severe shock occurs. Moreover, research on *competitive* risk-averse firms facing price uncertainty has shown that forward markets increase social welfare through another channel. Firms which without the possibility to trade forward would have reduced their output below the (full-certainty) competitive level, con-

[16] This setting thus resembles the wholesale segment in energy markets, where (most of the) buyers are retailers that compete with each other to sell to residential users.

tract the competitive amount in the forward market if possible (see e.g. Baron, 1970; Holthausen, 1979; and Sandmo, 1971).

Second, when commodity markets are *imperfectly competitive* forward contracts can potentially have an additional pro-welfare effect. The basic idea, developed by Allaz and Vila (1993), is that firms use forward contracts as strategic commitment devices. By contracting (part of) their output in advance of the delivery period, a firm takes a smaller position in the spot market. This reduces its incentive to maintain a high spot price, which implies that the firm commits to a more aggressive strategy in the spot market. As a result, rival firms will adhere to a less aggressive spot strategy which generates a competitive advantage for the contracting firm. However, since all sellers are interested in taking a short position in the forward market to affect their competitors' behavior in the spot market, they all end up playing a more aggressive strategy. Consequently, the final market outcome will be closer to the competitive one.

Some empirical support for the existence of this pro-competitive effect of forward trading in power markets is provided by Green (1999) and Wolak (2000). Studying the effect of vertical ties between wholesalers and retailers on market performance in three different U.S. electricity markets, Bushnell, Mansur and Saravia (2008) find evidence that wholesale firms which are vertically integrated or have long-lasting contractual arrangements with retailers behave more competitively than wholesalers which do not have strong links to downstream retailers. The reason for this is analogous to the intuition behind the result of Allaz and Vila: since retail prices in the markets studied by Bushnell *et al.* are rigid due to regulation or price commitments well in advance of delivery, vertically integrated firms sell part of their output against a fixed price. Again, this weakens the incentives to raise the price on the wholesale market.[17]

[17]Yet another reason why forward contracts with an extended duration may *ex ante* be more efficient than spot market trade is that these contracts avoid *ex post* bargaining. This relates to the well-known hold-up problem (Williamson, 1979), which occurs when one of the parties, say the seller, needs to invest in transaction-specific capital that cannot be used for other purposes (e.g. dedicated pipelines connecting production sites and the transmission network). If the buyer and seller repeatedly negotiate the terms of trade in short-term markets, the buyer has an incentive to renegotiate the terms of trade in order to obtain (part of) the rents from the seller's investment once the transaction-specific capital is in place. The seller is thus unable to appropriate all rents from his investment, and as a result, he will underinvest. If, on the contrary, the seller and the buyer are locked into a long-lasting relationship due to a (renegotiation proof) contractual agreement, the seller is protected against opportunistic actions of the buyer as far into the future as the duration of the contract. Joskow (1987), studying bilateral contracts between coal producers and electricity utilities, finds empirical evidence that long-term contracts can be a solution to the hold-up problem.

The limited empirical evidence on the pro-competitive effect of forward contracts stems from markets where regulators have imposed obligations on large suppliers to sell part of their production (capacity) on a forward basis, often in the form of gas release programs and virtual power plants (VPPs). Therefore, whether forward institutions by themselves provide market players with sufficient incentives to trade forward is not well-understood yet. In addition, there exist other complicating factors that have precluded the proliferation of empirical work on forward contracting. For instance, due to confidentiality reasons it is difficult to get one's hands on data about contracts. Further, even when equipped with a rich data set disentangling the various incentives to sell forward becomes a challenging task.

In the third chapter of this thesis, we show how the econometrician can empirically disentangle the different motives for forward contracting when having sufficient data at hand. Exploiting the equilibrium restrictions from an underlying model, we propose an empirical strategy to test whether sellers trade forward for risk-hedging reasons, for strategic motives, or both. Whether forward contracts can be used for strategic purposes crucially depends on their observability, as is shown by Kao and Hughes (1997). Therefore, market transparency is a necessary condition for the strategic motive of forward contracting to be present. Given that forward transactions are usually conducted anonymously, it is nearly impossible that suppliers become directly informed about their rivals' forward positions. However, by looking at (changes in) forward prices market players could in principle be able to infer (aggregate) positions in the forward market. This suggests that the provision of reliable price information plays an important role in developing more competitive markets. In current gas markets, information about forward prices is delivered by information agencies, brokers' associations and exchanges, typically in the form of price indices. The question then becomes whether market players are able to extract the necessary information from price indices, given that these indices are complex statistics, based on prices of a broad range of contracts that differ from each other in terms of duration, traded volume and so forth.

Thus, the extent to which strategic commitment through forward contracting is possible varies from market to market, depending on the prevailing level of transparency. When equipped with the adequate data set, the empirical strategy laid down in Chapter 3 provides the researcher with a way to test for the presence of strategic and/or risk-hedging incentives in a forward market. We show that identi-

Using data from 277 contracts, he obtains the result that when relationship-specific investments are more prominent, the duration of the contract is longer. That is, if the parties involved invest in transaction-specific capital they rely more on long-term contracts and less on repeated bargaining.

fication of the strategic motive relies on variation in the number of active suppliers in the market. If the market is relatively transparent so firms can sell forward for strategic reasons, the theoretical model predicts that entry of new firms leads to a fall in the inverse hedge ratio of suppliers. By contrast, if the forward market is relatively opaque we expect the inverse hedge ratio to go up in the number of active sellers.

In Chapter 4, we apply this strategy to the Dutch wholesale market for natural gas. One of the most notable deregulation steps in this market was the opening of the Title Transfer Facility (TTF) in 2003. The TTF is a virtual trading hub where gas can easily change hands before it is taken out of the Dutch pipeline network at a certain exit point. The existence of the TTF enabled the arrival of gas exchanges for spot contracts (APX) and futures (ENDEX).[18] Our data set consists of a large share of all (forward, spot and speculative) transactions that have been conducted at the TTF, for the period April 2003 through June 2008. We also have data on the number of active wholesalers for this period. Our empirical results suggest that suppliers at the TTF engage in forward contracting for strategic purposes. Given that most of this trade takes place in over-the-counter (OTC) markets, we believe this is an important result. OTC markets are often criticized for being relatively opaque, providing only little information about market conditions to participants. The Dutch forward market for natural gas however seems to be relatively transparent, because if not, forward contracts could not have been traded for strategic commitment reasons.

The introduction of centralized exchanges

Finally, we take a closer look at the market microstructure of energy markets, where we particularly focus on the role of organized exchanges in restructured energy markets.[19] As markets for commodities have been created, the rather homogeneous nature of energy commodities makes it possible to standardize energy contracts which can be traded at centralized marketplaces. In recent years we have indeed witnessed the opening of various energy exchanges at the wholesale level, where market parties are typically offered the opportunity to trade spot contracts as well as energy derivatives, like futures and options. These exchanges usually operate business-to-business (B2B) platforms, which enable buyers and sellers to meet in the virtual marketplace. The emergence of B2B e-commerce is due to the information technology revolution,

[18] For some more information about the Dutch gas market and the TTF, we refer the interested reader to Chapter 4.

[19] The theory of market microstructure studies institutional issues related to intermediation and exchange (see e.g. Spulber, 1996).

as B2B trade is conducted electronically, predominantly through the web (see e.g. Lucking-Reiley and Spulber, 2001). In order to be able to make use of the services provided by the exchange, market parties usually have to subscribe to the exchange's website.

The first and foremost *raison d'être* of centralized exchanges is the provision of intermediation services, thereby facilitating buyers and sellers to find a counterparty. By automating the processing of transaction-related data through the Internet or electronic data interchange, e-commerce lowers the cost for buyers and suppliers to conduct a transaction (Borenstein and Saloner, 2001). Further, B2B marketplaces typically reduce the counterparty risk for traders by providing immediacy and clearing services.[20] Immediacy is usually provided by exchange brokers, who, by holding cash and inventory to stand ready to buy and sell, allow traders to conduct a deal immediately. This alleviates the *double coincidence of wants* problem, because the buyer and seller are no longer required to transact at the same moment in time. Clearing reduces a trader's risk of nondelivery or nonpayment in case of default by a counterparty, as clearing activities include the netting of offsetting positions, monitoring the creditworthiness of trading parties and requiring traders to keep a collateral deposit.[21]

These benefits from electronic B2B trade thus have the potential to lure many buyers and sellers to the organized exchange. This has a reinforcing effect on the incentives to become active at the exchange, as buyers and sellers gain from finding more traders from the other side of the market at the centralized marketplace. This is due to two reasons. First, a high level of activity at the exchange increases the likelihood that a single trader finds a trading partner. This market liquidity lowers the cost of searching for a counterparty, while at the same time eliminates a trader's price risk from delaying a transaction (Grossman and Miller, 1988).[22] Second, as transactions at organized exchanges are based on a bidding mechanism an increase in the number of participants intensifies competitive pressures at both sides of the

[20] See Spulber (1996) for a broad discussion on the various services that are provided by B2B intermediaries.

[21] Another potential advantage of organized exchanges is the relatively high degree of transparency in these institutions, providing important information about trading conditions to market participants. As mentioned above, the importance of market transparency is dealt with in Chapters 3 and 4 of this thesis.

[22] As explained above, liquidity is sometimes provided by brokers who stand ready to buy or sell at any moment. When transactions conducted on the B2B platform are not intermediated by a broker, the exchange itself has to be sufficiently liquid to ensure buyers and sellers that they do not run the risk of not being matched with a counterparty.

market.

Chapter 5 examines how the degree of liquidity and competition on electronic exchanges influences the decisions of market players to move away from bilateral negotiations and start trading on the centralized marketplaces. Though B2B platforms have the potential to deliver the benefits mentioned above, at first glance it is not clear that buyers and sellers always want to bypass the OTC market. For instance, given that organized exchanges only facilitate trade in standardized products with a high turnover rate, there may exist an incentive for traders to acquire more custom-made products in the decentralized market. This is especially an issue when market participants face idiosyncratic risk than cannot be hedged by the standardized contracts offered at the centralized marketplace (Duffie, Gârleanu and Pedersen, 2007; Duffie, Li and Lubke, 2010).

In Chapter 5, we show that an additional reason to rely on one-to-one negotiations instead of trading at an exchange is the ability to price discriminate in the OTC market. Letting buyers differ in their valuation for the product that is traded, we establish that in equilibrium both market institutions exist: high-valuation buyers, losing a large part of their surplus when being exposed to price-discriminating sellers, are willing to pay the exchange fee in order to trade at the B2B platform; low-valuation buyers, by contrast, turn to the decentralized market as they only have to give up a relatively small amount of the trading surplus as a result of bargaining.

Our finding that over-the-counter markets and organized exchanges can exist side by side is interesting given the fact that most other work on this topic suggests that in equilibrium trade takes place on only one of the two marketplaces. For instance, Baye and Morgan (2000; 2001), considering identical firms facing the problem of selling their product to homogeneous consumers on either local markets or a centralized website operated by a gatekeeper, come to the result that the gatekeeper sets subscription fees that lure all buyers to the centralized platform. This also implies that all transactions are conducted through the website, leaving the local markets empty. Considering firms that offer differentiated products instead of homogeneous goods, Galeotti and Moraga-González (2009) also establish that the platform manager charges both sides of the market such that all trade takes place on the platform. Our model differs from the settings studied by Baye and Morgan and Galeotti and Moraga-González in that we assume that consumers are heterogeneous in their willingness to pay, which allows suppliers to engage in price discrimination in over-the-counter negotiations. This makes the OTC market for some buyers relatively more attractive than for others, hence we obtain segmentation on the buyer's side of the market.

We take the view that buyer segmentation indeed plays a role in present energy markets. Despite the aim of policy makers to develop highly liquid energy exchanges, we observe that most energy contracts are still transacted over-the-counter. For example, as is also discussed in more detail in Chapter 4, the Dutch gas market is currently characterized by a fairly low share of centralized trade. In 2008, about 20 percent of the high-calorific gas transacted in the Netherlands passed the TTF. Concerning trade in the power sector, we note that volumes bought and sold at the European electricity spot exchanges EEX (Germany), APX (The Netherlands) and Powernext (France) accounted for respectively 17, 13 and 4 percent of total national consumption in 2008 (see EC, 2007). Even in countries where energy exchanges have matured, a sizeable number of transactions takes place in decentralized marketplaces. For instance, about 67 percent of the 2007 U.K. gas consumption passed the National Balancing Point (NBP), which is the natural gas hub in the U.K. However, a substantial part of the NBP transactions are conducted over-the-counter.

It seems reasonable to believe that the coexistence of centralized and decentralized trade in energy markets is due to the presence of various types of buyers who differ in their valuation for the energy source. Considering the wholesale market for natural gas, we notice that the buyer's side consists of a variety of different types of buyers, like retailers, industrial users and speculative traders. In this respect, it is interesting to see that in the Dutch gas market industrial users fully rely on the OTC market when buying gas and thus ignore the centralized hub TTF completely. The decentralized market may be more attractive for this type of consumers because OTC-traded contracts provide the necessary level of flexibility these buyers require, but it could also be due to industrial users having a relatively low willingness to pay for gas. Given that industrial costumers like electricity producers usually have the opportunity to substitute away the use of gas in their production process if the gas price becomes too high, this seems to be a plausible explanation.

The discussion above has already touched upon the main issues we study in the core of this thesis, which consists of Chapters 2 through 5. The thesis ends with a chapter containing the main conclusions and policy recommendations that follow from our research. That chapter also provides some ideas for further research.

Chapter 2

Transportation pricing and market power in the natural gas industry*

2.1 Introduction

In the thesis introduction, we have stated that in the pre-liberalization period energy industries were vertically integrated monopolies, state-owned or not, operating under regulatory constraints. Owing to the recent trend of privatization and liberalization in network industries, separation of transportation services from commodity production and distribution has taken place in a number of gas and electricity markets. In the production and distribution segments policymakers attempt to promote competition by facilitating market entry by emerging firms. To ensure successful entry into the market, pipelines and power networks must grant access to the transportation system to new players. After a process of entry and exit, in recent days, the gas and electricity markets are essentially oligopolistic, with a few firms operating at the supply side of the market. Transportation services usually remain regulated because of the natural monopoly characteristics of most services offered by the transmission system operator (TSO).

In the gas industry, the scope for competition depends on the extent to which gas suppliers can access pipelines. Transport capacity and access prices are two impor-

*This chapter is based on van Eijkel, Haan and Moraga-González (2010).

tant instruments for regulators to increase competitive pressures in the gas market. Since capacity of the pipelines is somewhat fixed in the medium run and in any case rather costly to alter, attention has been given to the institutional details regarding the transportation of the commodity as well as to the pricing of transmission services.

Optimal transmission pricing has been studied thoroughly in the economics literature on power markets. The seminal work of Schweppe *et al.* (1988) shows that with perfect competition, in the absence of congestion, equilibrium prices are equal in all nodes of the power network. In the most simple case where the TSO bears no cost of providing services at all, optimal transportation tariffs are equal to zero. If one or more lines in the network become congested, then the price of transmission services is just the price difference between the nodes that are connected by the congested line. This pricing scheme, referred to as *nodal pricing*, implies that an energy supplier receives its local price for all energy sold, independent of where its output is consumed.

Although nodal pricing is optimal in a perfectly competitive environment, it has also been used in models studying market power in energy industries. For example, Borenstein, Bushnell and Stoft (2000) consider an electricity network in which generators have market power and assume the existence of a fringe of arbitrageurs which ensure there are no price differences between nodes if the network is not congested. When the network becomes congested, the transportation tariffs are again equal to the difference in prices. The crucial assumption in electricity studies using nodal pricing is that arbitrage opportunities are exhausted so there are no price differences across nodes in a non-congested network. Clearly, this assumption is justified if the market structure is one of perfect competition. However, in contrast to most electricity markets, possibilities for arbitrage across regions in the gas industry are still fairly limited. Among the most important institutional factors preventing the exercise of arbitrage in gas markets are the absence of liquid hubs, physical bottlenecks in the network, and shippers' contractual obligations *vis-à-vis* consumers (see EC, 2007).

Another feature that distinguishes the gas industry from the market for electricity is that the physical laws governing the transmission of the commodities over the networks are not the same. The technical distinction, put forward neatly by Wilson (2002, p. 1301), has economic consequences:

> *Power transfers are complicated by the difficulty of directing flows in transmission systems with alternating current. [...] The absence of point-*

> *to-point transmission has had the economic consequence that property rights are not assigned by title (in contrast, title to gas is tracked continuously, even though it is perfectly homogeneous). No one owns power per se; rather, qualified market participants obtain privileges to inject or withdraw power from the network at specific locations.*

The fundamental difference between the two markets is that while gas producers typically have control over the gas flows, power producers generally do not. As a result, a gas producer can decide where it will inject the gas in the system and where it will take it out, thus being able to target output plans to distinct gas markets. In electricity, by contrast, the decision of a producer of power is just how much to inject in the system. This dissimilarity between industries, together with the lack of full arbitrage, implies that the existing models of nodal pricing developed for the electricity sector do not apply straightforwardly to the gas industry.

In this chapter, we study the incentives of gas producers and the role of transportation prices to foster competition in the gas market. We consider a setting where two gas producers serve two distant markets connected by a pipeline, which is under control of a regulated TSO. Each producer is located at one of the ends of the pipeline and chooses gas supplies for the local and for the distant market. The fact that gas suppliers can control the gas flows in real-world markets has led to some important institutional details that we incorporate in our four-stage game. At the beginning of the market interaction, the TSO announces transmission tariffs for direct and reverse gas flows. In the second stage of the game, firms book transmission capacity for the gas they intend to sell in the distant market. In the third stage of the game, the TSO allocates transmission rights by netting out the reserved capacities and taking into consideration the overall pipeline capacity.[1] In the last stage, firms produce gas and inject it into the system; the consumers withdraw it and consume it.

Our model is similar in spirit to that in Cremer and Laffont (2002).[2] Their paper shows how the standard notion of nodal pricing has to be modified to account for the particular cost structure of gas pipelines.[3] The main differences are that we allow for market power in each node and that we do not adopt nodal pricing as the

[1]With netting, flows in opposite directions cancel out and the line only has to let through the (physical) net flow, that is, the difference between the booked flow from 1 to 2 and the booked flow from 2 to 1.

[2]A similar framework is used in Joskow and Tirole (2000) and Gilbert, Neuhoff and Newbery (2004) to study the role of transmission contracts in the power sector. Likewise, Borenstein, Bushnell and Stoft (2000) use this model to examine the effects of pipeline capacity in the electricity market.

[3]See also Cremer, Gasmi and Laffont (2003) for the case of competitive gas markets and a

transportation pricing system. These differences imply that the booking system for capacity and the allocation mechanism for transmission rights need to be spelled out in detail. If the transmission line had no capacity whatsoever, firms would be monopolists in their own local markets, while if capacity were sufficiently large, the market would be fully integrated and each firm would behave as a duopolist in a large global market. Pipelines of limited capacity and the possibility of netting give firms an incentive to restrict their transmission bookings thereby also restricting the actual exports of the rival firm and increasing local market power.

The first part of the chapter focuses on situations where pipeline capacity is large. In this case, a symmetric equilibrium exists in which flows are netted out so the pipeline is not fully utilized. In the absence of pipeline congestion, attaining the first-best calls for negative transportation prices, thus effectively lowering the cost of producing gas intended for exports and thereby raising exports till competitive levels. The first-best tariffs then correct for market power and are therefore smaller than corresponding first-best nodal prices (Cremer and Laffont, 2002). More interesting is the case in which the TSO operates under a budget constraint (second-best pricing). In this situation too, nodal pricing is not optimal: relative to nodal prices, a budget-constrained and welfare-maximizing TSO adjusts its transportation tariffs upwards to account for the presence of downstream market power. This is because gas producers with market power supply too little output relative to the competitive level, which implies that the tax base of the TSO is smaller and so nodal prices would generate a loss for the TSO. As a result, our second-best tariffs are higher than nodal prices. Finally, we examine the nature of profit maximizing transportation tariffs. We find that a profit-maximizing TSO charges tariffs that are too large from the viewpoint of society. This result arises because a profit-maximizing TSO does not internalize the effects of its tariffs on consumer's surplus and profits of the gas suppliers.

The second part of this chapter deals with the case where pipeline capacity is relatively small. In this situation, an (essentially) unique asymmetric equilibrium is shown to exist. Relative to the symmetric equilibrium, in this asymmetric situation one of the firms continues to lower its gas exports till the pipeline is congested. Interestingly, in equilibrium the commodity flows into the market where the price is lower. This result, which is at odds with the received wisdom from competitive markets, is not only a theoretical curiosity but has been observed in real world gas markets. For example, in the Interconnector,[4] a two-way pipeline that links the U.K.

three-node network.

[4]See www.interconnector.com.

(Bacton) and continental Europe (Zeebrugge), net flows have been seen to go from the U.K. to Belgium in a period where U.K. gas prices were significantly higher.[5] Our analysis suggests that this outcome can be a natural result of profit-maximizing behavior when demand is large relative to pipeline capacity.

In this case of small pipeline capacity where the equilibrium features pipeline congestion, it turns out that a budget-constrained and welfare-maximizing TSO has an incentive to subsidize the reverse flow and tax the dominant one. This second-best tariffs are meant to weaken the incentives of a firm to congest the pipeline in equilibrium, so that total supply on both markets increases and so does welfare. Since in equilibrium gas flows differ across markets, transportation tariffs are not equal to one another in absolute value. Therefore, also in this case of absence of excess pipeline capacity, our second-best tariffs differ from nodal prices.

In sum, our analysis shows that the market outcome, and so the nature of transportation pricing, crucially depends on the capacity of the pipeline. During summer seasons, demand is expected to be relatively low compared to capacity and so distinct geographic markets are expected to exhibit similar commodity prices. By contrast, if pipelines have not sufficient capacity, tough winters may lead to asymmetric equilibria and therefore to significant price differentials across separated geographic markets. Our results on optimal pricing suggests transportation tariffs should be seasonal and, moreover, discriminatory when there is pipeline congestion.

The remainder of this chapter is organized as follows. In the following section we describe in detail the model we use for our analysis. In Section 2.3, we consider the case of no congestion and demonstrate that socially optimal tariffs differ from nodal prices. We also provide tariffs that maximize the profits of the TSO. Section 2.4 discusses second-best transportation prices when there is congestion and shows that in this case, tariffs are again not equal to nodal prices. Building on Sections 2.3 and 2.4, we derive the subgame perfect equilibrium of the game in Section 2.5. Finally, Section 2.6 deals with asymmetric markets and Section 2.7 concludes. All proofs are relegated to the Appendix.

2.2 The model

We consider a gas network that consists of two nodes, labelled 1 and 2, which are connected by a pipeline with capacity K. There is demand for gas as well as gas

[5] In fact, this triggered a European Commission competition investigation of the operation of the Interconnector during January 2001 (see EC, 2002).

production in both nodes. We focus on the case of symmetric demand, so $P_1(\cdot) = P_2(\cdot) = P(\cdot)$. Assume the common demand function is given by

$$P(Q_i) = a - Q_i,$$

where Q_i is the aggregate quantity of gas consumed in node i with $i = 1, 2$. In each node, gas is produced by a single firm, where firms are indexed by $i = 1, 2$. Due to the existence of the transmission line a producer cannot only sell gas in its local market but also in the distant market.[6]

To make clear the distinction between a producer's supply for its local market and its output targeted to the distant node, we refer to q_{ij} as the total output of a firm located in node i to serve demand in node j. Then $Q_1 = q_{11} + q_{21}$ and $Q_2 = q_{12} + q_{22}$. For the sake of clarity, q_{ii} and q_{ij}, $i \neq j$, are referred to as *local supply* and *exports* of firm i, respectively. In case the pipeline capacity is insufficient to accommodate the desired exports of the producers, a specific rationing rule has to be used by the TSO. We will introduce this rationing rule below when we spell out the booking system for transmission rights in the gas industry. The marginal cost of supplying gas (net of transportation charges) equals c for all firms, irrespective of whether it concerns domestic supply or exports. The cost function of firm i equals

$$C_i(q_{ii}, q_{ij}) = c(q_{ii} + q_{ij}) + t_{ij}q_{ij}, \text{ with } i \neq j \text{ and } i, j = 1, 2,$$

where t_{ij} denotes the linear transportation tariff firms are charged to get one unit of their gas shipped from node i to j. Note that the pipeline is needed for gas exports and that firms can sell locally without using it. We shall assume that $|t_{ij}| \leq (a-c)/2$; if this assumption were not satisfied markets would be served by monopolies and the problem would not be so interesting.[7]

We consider a TSO having control over the pipeline and being able to charge firms for the use of the transportation services. Throughout the chapter, we treat pipeline capacity as exogenous and assume that past investment outlays for capacity are sunk costs. The only costs for the TSO arise from shipping the (net) gas flow over the line and from pipeline maintenance; let c_O be the constant marginal cost of transporting the gas and C_K the fixed costs necessary to maintain the network

[6] Here we notice the difference between the gas industry and the market for electricity: while in the latter producers receive the local price for the total amount sold and therefore cannot sell in different consumer markets, in the former firms have the ability to target their output to geographically distinct markets.

[7] We get that if tariffs are very large, demand in a particular node is served only by the local firm. In contrast, when transportation prices become sufficiently negative there is no local supply and exports cover total demand in both nodes.

operational. The pipeline is used by firms only to ship gas to the distant market. Moreover, as gas is completely homogeneous we assume that the operator is able to net out gross exports against each other. As a result, pipeline capacity has to be sufficiently large to let through the net flow, which equals the difference in gross exports, or $|q_{21} - q_{12}|$. The cost function of the TSO is then as follows:

$$C_O(q_{12}, q_{21}, K) = c_O\,|q_{21} - q_{12}| + C_K.$$

The core of the analysis focuses on the case in which the TSO is perfectly controlled by a welfare-maximizing regulator. As will become clear later, the first-best outcome would entail a loss for the TSO. To circumvent this problem, we let the TSO maximize welfare under the constraint that it has to break even. The resulting second-best tariffs are known as Ramsey-Boiteaux prices (see e.g. Laffont and Tirole, 2002). This chapter also presents a comparison of profit-maximizing transportation prices with socially optimal tariffs.

We model the interaction in the market as a four-stage game. In the first stage, the TSO decides on transportation prices t_{ij} with $i \neq j$ and $i, j = 1, 2$. In the second stage, firms book transmission capacity to be able to export gas to the distant node. Let us denote these bookings by b_{ij} with $i \neq j$ and $i, j = 1, 2$. Then, in the third stage of the game, the TSO allocates transmission rights $\bar{b}_{ij}$ to the firms taking into account the transport capacity of the pipeline and the possibilities for netting the flows. In the last stage, production is realized and firms compete on both markets given their transmission rights and the tariffs set by the operator. In line with the actual practice in the industry, we assume that penalties for imbalances ensure that actual exports are always equal to the transmission rights granted to the firm, that is, $q_{ij} = \bar{b}_{ij}$. We define the last three stages of the game as the *gas market subgame*, since throughout the chapter these stages are discussed together. The game is solved by backward induction.

In what follows, we derive the subgame perfect equilibria (SPE) of this model. We first consider the case where in the gas market subgame, producers play strategies that yield an equilibrium in which the pipeline is not congested. Then, we determine for this gas market equilibrium first-best, second-best, and profit-maximizing tariffs. Thereafter, we move to the situation in which firm do bookings that lead to pipeline congestion and solve for the second-best tariffs.

2.3 Non-congested pipeline

In this section we study pipeline access in situations where the capacity of the pipeline is large and therefore there is no congestion in the market. We first consider the downstream gas market subgame. Then we solve for the socially optimal and profit-maximizing transportation tariffs.

2.3.1 Equilibrium in the gas market

Here we characterize firm strategies that are part of an equilibrium without congestion. Proceeding backwards, we start with the last stage of the game. In this stage, taking as given the transportation tariffs set by the TSO and the transmission rights allocated to the firms, both gas producers compete in quantities. A firm i chooses the pair (q_{ii}, q_{ij}) to maximize its profits, which are given by

$$\pi_i(q_{ii}, q_{ij}; \cdot) = (a - (q_{ii} + q_{ji}) - c)q_{ii} + (a - (q_{ij} + q_{jj}) - c - t_{ij})q_{ij}.$$

The existence of penalties for imbalances between the actual exports of a firm and its transmission rights ensures that firms do not withhold transmission rights in equilibrium, i.e. $q_{ij} = \bar{b}_{ij}$. This has the implication that the booking system serves as a commitment device and confers the rival exporter a first-mover advantage over its local counterpart. Therefore, the local supply q_{ii} of firm i is the best reply to the transmission rights allocated to firm j, i.e. $q_{ii} = BR(q_{ji}) = BR(\bar{b}_{ji})$. Equilibrium strategies in this stage are then as follows:

$$\begin{aligned} q_{ii}(\bar{b}_{ji}) &= \begin{cases} \frac{a-\bar{b}_{ji}-c}{2} & \text{if } \bar{b}_{ji} < a-c \\ 0 & \text{otherwise} \end{cases} \\ q_{ij}(\bar{b}_{ij}) &= \bar{b}_{ij}, \end{aligned} \tag{2.1}$$

with $i \neq j$ and $i, j = 1, 2$.

We now move to describe the equilibrium of the third stage of the game. In this stage, anticipating that actual exports will be equal to the transmission rights allocated to the players, the TSO assigns transmission rights. For this, the TSO takes into account the capacity of the pipeline and the desired net export flow. Consider first a situation where firms request transmission rights b_{12} and b_{21} such that the net flow does not exceed the capacity of the pipeline. In this case, the amount of transmission rights granted to the firms equals the booked capacity. In case line capacity is not large enough to let through the desired net flow, the TSO rations the firm requesting the largest amount of transmission rights. In particular, this firm is allocated the maximum transmission capacity which is compatible with pipeline capacity.[8] Therefore, the equilibrium TSO's mechanism for transmission rights allocation is

$$(\bar{b}_{12}, \bar{b}_{21}) = \begin{cases} (b_{12}, b_{21}) & \text{if } |b_{21} - b_{12}| < K \\ (b_{12}, b_{12} + K) & \text{if } b_{21} - b_{12} \geq K \\ (b_{21} + K, b_{21}) & \text{if } b_{12} - b_{21} \geq K. \end{cases} \tag{2.2}$$

We now move to the second stage of the game. In this stage, firms book transmission capacities to maximize profits taking into account transportation tariffs and anticipating the equilibrium strategies in the continuation game. Consider the strategy profile (b_{12}, b_{21}). Figure 2.1 shows the congesting nature of different strategy profiles. When the difference between b_{12} and b_{21} does not exceed K, there is no congestion; otherwise either firm 1 or firm 2 is rationed by the TSO according to (2.2).

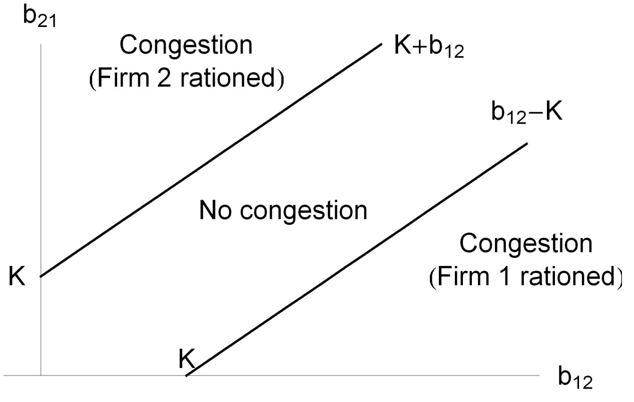


Figure 2.1: Booking strategies, pipeline congestion and implied rationing

While studying whether a pair of booking strategies can be part of an equilibrium, it is useful to distinguish between booking profiles which result in no congestion of the pipeline and booking profiles resulting in congestion. We start by considering the set of booking profiles in the "No congestion" region of Figure 1. Later in Section 2.4 we consider booking strategy profiles which lead to pipeline congestion.

Let us study whether a booking profile (b_{12}, b_{21}) satisfying $|b_{21} - b_{12}| < K$ can be part of an equilibrium. Consider the problem of firm i. This firm chooses a booking b_{ij}

[8]This rationing rule is the only possible one in our model, since the TSO cannot force the firm that is booking the smallest amount to book more.

to maximize its profits taking into account firm j's booking as well as the equilibrium strategies in the continuation game. Under the assumption $|t_{ij}| < (a-c)/2$, the reduced-form second-stage profits of firm i would be

$$\pi_i = \left(\frac{a - b_{ji} - c}{2}\right)^2 + \left(\frac{a - b_{ij} - c}{2} - t_{ij}\right) b_{ij},\ i \neq j,\ i,j = 1,2,$$

where we note that $\bar{b}_{ij} = b_{ij}$ and $q_{ii} = BR(q_{ji})$. Taking the FOC and solving for b_{ij} gives

$$b^*_{ij} = \frac{a - c - 2t_{ij}}{2},\ i \neq j,\ i,j = 1,2. \tag{2.3}$$

Equation (2.3) describes the optimal capacity bookings of the firms (provided transportation rates are lower than $(a-c)/2$ for otherwise firms would prefer not to export at all). Note that booking the amounts in (2.3) does not lead to pipeline congestion as long as $|t_{21} - t_{12}| < K$.

If these strategies were part of an equilibrium, aggregate production, prices and profits would be given by

$$Q^*_i = b^*_{ji} + q^*_{ii} = \frac{3(a-c) - 2t_{ji}}{4} \tag{2.4}$$

$$p^*_i = \frac{a + 3c + 2t_{ji}}{4} \tag{2.5}$$

$$\pi^*_i = \frac{(a - c + 2t_{ji})^2}{16} + \frac{(a - c - 2t_{ij})^2}{8},\ i \neq j,\ i,j = 1,2. \tag{2.6}$$

We note that these outcomes do not depend on K, since there is no congestion and both firms are able to ship to the distant market their desired levels of exports.

We now examine the conditions under which firms cannot profitably deviate from the strategies in (2.3). We first consider a deviation by firm 1. Given firm 2's equilibrium booking b^*_{21}, consider firm 1 deviates by lowering its booking so as to generate pipeline congestion, i.e, firm 1 deviates by booking an amount $b^d_{12} \in [0, b^*_{21} - K)$.[9] This deviation is potentially profitable for firm 1 because by doing so this firm in effect controls the amount of exports flowing into its market, which increases its local market power.

In the third stage, following the deviation by firm 1, the TSO allocates transmission rights to the firms equal to $\bar{b}_{12} = b^d_{12}$ and $\bar{b}_{21} = b^d_{12} + K < b^*_{21}$. Therefore, the deviant's reduced-form profits equal

$$\pi^d_1(b^d_{12}, b^*_{21}) = \left(\frac{a - b^d_{12} - K - c}{2}\right)^2 + \left(\frac{a - b^d_{12} - c}{2} - t_{12}\right) b^d_{12}. \tag{2.7}$$

[9] Note that $b^d_{12} < b^*_{21} - K$ must hold, since otherwise firm 2 still gets transmission rights allocated equal to b^*_{21} and there would be no congestion.

Taking the FOC and solving for the optimal deviation yields

$$b_{12}^d = \begin{cases} K - 2t_{12} & \text{if } t_{12} < K/2 \\ 0 & \text{otherwise.} \end{cases}$$

Using this optimal deviating strategy, one obtains the profits of the deviant:

$$\pi_1^d(\cdot) = \begin{cases} \frac{1}{4}(a-c-K)^2 + \left(\frac{K}{2} - t_{12}\right)^2 & \text{if } t_{12} < K/2 \\ \frac{1}{4}(a-c-K)^2 & \text{otherwise.} \end{cases} \tag{2.8}$$

Comparing equilibrium profits in Equation (2.6) with deviating profits in Equation (2.8) yields

$$\pi_1^*(b_{12}^*, b_{21}^*) \geq \pi_1^d(b_{12}^d, b_{21}^*) \Leftrightarrow K \geq K_1(a, c, t_{12}, t_{21}), \tag{2.9}$$

where

$$K_1(\cdot) \equiv \begin{cases} \left(1 - \frac{1}{\sqrt{2}}\right)\frac{a-c}{2} + t_{12} - \frac{t_{21}}{\sqrt{2}} & \text{if } t_{12} < A(t_{21}) \\ a - c - \frac{1}{2}\sqrt{3(a-c)^2 + 4(a-c+t_{21})t_{21} - 8(a-c-t_{12})t_{12}} & \text{otherwise} \end{cases} \tag{2.10}$$

and $A(t_{21}) \equiv \left(1 - \frac{1}{\sqrt{2}}\right)\frac{a-c}{2} - \frac{t_{21}}{\sqrt{2}}$.

Proceeding analogously, we can compute the condition under which firm 2 does not deviate from the equilibrium strategy in Equation (2.3). This condition is symmetric to the condition in (2.9) and therefore $K_2(\cdot)$ can be obtained from the expression for $K_1(\cdot)$ by interchanging the subindices i and j.

We are now ready to state our first equilibrium result. For this purpose, we define the set of parameters

$$Z_{NC} \equiv \{(a, c, t_{12}, t_{21}, K) : K \geq K_1(\cdot);\ K \geq K_2(\cdot)\}. \tag{2.11}$$

We then come to the following proposition:[10]

Proposition 2.1 *For any vector of parameters $(a, c, t_{12}, t_{21}, K) \in Z_{NC}$ there exists a downstream gas market equilibrium where firms book the amounts given in (2.3), transmission rights satisfy (2.2) and production levels are given by (2.1). In equilibrium, the net flow is less than K so there is no congestion. Firms obtain a profit given in (2.6).*

[10]Note from (2.3) that a necessary condition for an equilibrium without congestion to exist is $|t_{21} - t_{12}| < K$. It is easy to see that this condition is satisfied if $(a, c, t_{12}, t_{21}, K) \in Z_{NC}$. Suppose, without loss of generality, $t_{12} \leq t_{21}$ so that $K_1(\cdot) \leq K_2(\cdot)$ and therefore that $(a, c, t_{12}, t_{21}, K) \in Z_{NC}$ if $K \geq K_2(\cdot)$. Simple computation shows that $K \geq K_2(\cdot) > |t_{21} - t_{12}|$, which implies that $|t_{21} - t_{12}| < K$ automatically holds when $(a, c, t_{12}, t_{21}, K) \in Z_{NC}$.

In this equilibrium, firms do not have an incentive to congest the line and thus play strategies *as if* pipeline capacity were unlimited.

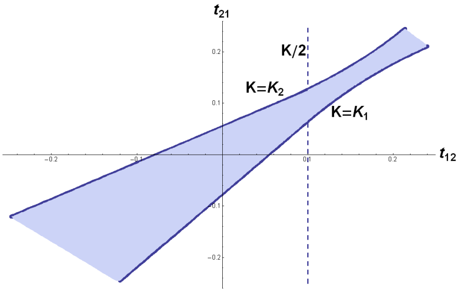
To illustrate Proposition 2.1, Figures 2.2(a) and 2.2(b) show, for given a, c, and K, the space of transportation prices (t_{12}, t_{21}) for which a downstream market equilibrium with no congestion exists. Figure 2.2(a) is drawn for the case of relatively large pipeline capacity, while Figure 2.2(b) shows the case of small capacity. In both cases, for pairs of tariffs (t_{12}, t_{21}) that lie between the two bounds $K = K_1(\cdot)$ and $K = K_2(\cdot)$, the equilibrium described in Proposition 2.1 exists.

To get some intuition, consider the bound $K = K_1(\cdot)$. For all tariff combinations that lie on this bound, firm 1 is indifferent between deviating from the strategy given by Equation (2.3) or not. Clearly, for any t_{12} to the left of this bound firm 1 strictly prefers not to deviate, since a lower t_{12} raises the profitability of exporting to market 2. Furthermore, any t_{21} above $K = K_1(\cdot)$ also makes that firm 1 does not have an incentive to deviate. This is because a higher t_{21} lowers the exports of firm 2 in case the line is not congested. Thus, for any pair of tariffs to the left and above of $K = K_1(\cdot)$ firm 1 does not have an incentive to deviate. A similar reasoning applies for the bound $K = K_2(\cdot)$: firm 2 does not deviate from the equilibrium strategy if the pair of tariffs is below and to the right of $K = K_2(\cdot)$.

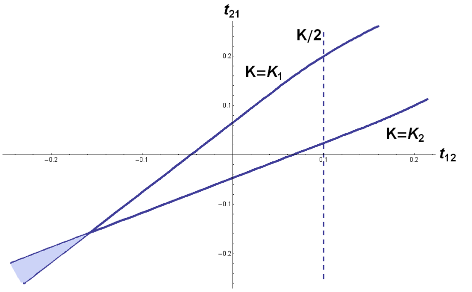
A comparison of Figures 2.2(a) and 2.2(b) reveals that the set of tariffs for which an equilibrium without congestion exists depends on pipeline capacity. When capacity is small, only negative transportation prices ensure that the pipeline is not congested (Figure 2.2(b)). The reason for this is that negative tariffs act as an export subsidy, which reinforces the incentives for firms to export a lot and makes congestion less attractive. By contrast, when capacity is large, positive transportation tariffs also allow for an equilibrium without congestion (Figure 2.2(a)). This is because when capacity is sufficiently large, it is not profitable for a firm to provoke congestion by lowering exports since the rival firm is anyway able to export an amount equal to (or close to) the desired amount.

2.3.2 Transportation pricing

Moving back to the first stage of the game, we now examine socially optimal transportation prices. We first consider the benchmark case of first-best transportation tariffs, then we study second-best tariffs. Finally, we discuss profit-maximizing transportation prices.



(a) Large pipeline capacity ($K = 0.2$)



(b) Small pipeline capacity ($K = 0.1$)

Figure 2.2: An equilibrium with no congestion exists in the shaded areas ($a = 2; c = 1$)

Social welfare is given by

$$\begin{aligned} SW &= \int_0^{Q_1} \Big(a - x - c\Big) dx + \int_0^{Q_2} \Big(a - x - c\Big) dx \\ &- C_O(q_{12}, q_{21}, C_K), \end{aligned} \tag{2.12}$$

where $C_O(\cdot) \equiv c_O|q_{21} - q_{12}| + C_K$ is the total cost of the TSO. Notice that changing either transportation tariff has no direct effect on the level of social welfare. This is because transportation prices are just transfers from the firms to the TSO. However, transportation prices have a bearing on welfare via the quantities firms put in the market.

First-best tariffs

Without any restrictions on the revenues of the TSO, the problem of the operator is to set tariffs that maximize Equation (2.12). Simple computations show that the first-best transportation prices equal

$$t_{12} = t_{21} = -\frac{a - c}{2}. \tag{2.13}$$

To attain the socially optimal allocation, access charges should be negative. This is because negative transportation tariffs result in an increase in the exports, which has a positive effect on welfare. Note that with these transportation tariffs firms export an amount equal to the competitive output and do not supply any gas locally.[11]

[11]Note that a similar aggregate outcome could be obtained if the government directly subsidized gas production instead of gas transportation. In that case, however, total public funding needed to

Finally, we note that in our model transportation tariffs are used to stimulate production so they differ in nature from nodal prices. In fact, while in our case first-best transportation pricing entails the use of subsidies, first-best nodal prices are equal to zero (see e.g. Cremer and Laffont, 2002).

Second-best tariffs

The previous section shows that in order to obtain the first-best solution, the TSO has to set negative transportation prices. However, this pricing scheme entails losses for the TSO. To get around this problem, we now assume that the TSO is not allowed to run a deficit.

The budget constraint of the TSO is given by

$$t_{12}q_{12} + t_{21}q_{21} - C_O(\cdot) \geq 0. \tag{2.14}$$

The TSO then maximizes (2.12) subject to (2.14), where the latter holds with equality at the optimum.[12] The resulting second-best transportation tariffs are Ramsey-Boiteaux prices, although adjusted for the presence of imperfect competition.

We consider the subset of tariffs that lead to the non-congested equilibrium (NCE) and ask which tariffs yield the highest level of social welfare. This subset has been denoted Z_{NC} and its characterization is given in Proposition 2.1. Assume, without loss of generality, that $t_{12} \geq t_{21}$; this implies $q^*_{12} \leq q^*_{21}$, so that the problem of the TSO can be written as

$$\max_{(t_{12},t_{21})\in Z_{NC}} \quad \{SW = \int_0^{Q_1^*(t_{21})} \Big(a - x - c\Big)dx + \int_0^{Q_2^*(t_{12})} \Big(a - x - c\Big)dx - C_O(\cdot)\}$$

subject to:

$$t_{12}q^*_{12}(t_{12}) + t_{21}q^*_{21}(t_{21}) - C_O(\cdot) = 0$$

$$t_{12} \geq t_{21}.$$

We then come to the following result.

Proposition 2.2 *For fixed parameters* a, c, K, c_O, C_K *consider the set* $T_{NC}(a, c, K, c_O, C_K)$ *of TSO's-budget-constraint-satisfying tariff combinations*

obtain the social optimum would be lower. In fact, the production tax should be set to $t = -(a-c)/3$ and the total government expenditures would be $(a-c)^2/3$.

[12] To see that the budget constraint is binding at the optimum, suppose by contradiction that this constraint does not bind. But then one of the tariffs (or both) can be lowered without violating the budget constraint, since this constraint is continuous everywhere. Lowering the tariff increases welfare, which implies that the budget constraint binds at the optimum.

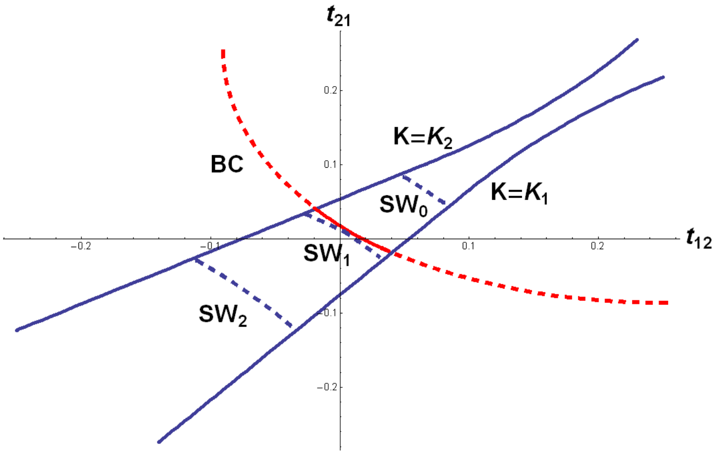


Figure 2.3: Optimal tariffs in the equilibrium without congestion ($a = 2, c = 1, K = 0.2, c_O = 0.01, C_K = 0.01$)

that lead to the NCE of Proposition 2.1:

$$T_{NC}(a, c, K, c_O, C_K) \equiv \{(t_{12}, t_{21}) \in R^2 : (t_{12}, t_{21}) \in Z_{NC}(a, c, K); \sum t_{ij} q^*_{ij} \geq C_O\},$$

with q^*_{ij} *given in Proposition 2.1. If* $T_{NC}(a, c, K, c_O, C_K)$ *is non-empty, the pair of tariffs*

$$t^*_{12} = t^*_{21} = \frac{a - c - \sqrt{(a-c)^2 - 8C_K}}{4} \tag{2.15}$$

dominates in terms of social welfare all other elements in this set $T_{NC}(a, c, K, c_O, C_K)$*.*

The proof is in the Appendix.

Proposition 2.2 gives the transportation prices (t^*_{12}, t^*_{21}) that maximize social welfare given that firms play strategies that lead to the equilibrium without congestion in the continuation game. It is easy to see that these tariffs are (i) increasing in the cost of the gas suppliers and in the cost of capacity, and (ii) decreasing in the demand parameter a.[13] When there is no cost of capacity (maintenance), these tariffs are equal to zero. In smaller markets, the tax base is smaller so tariffs have to be raised to be able to cover capacity costs.

The problem of the TSO and the reason why it chooses tariffs (t^*_{12}, t^*_{21}) can be illustrated by Figure 2.3. This Figure builds on Figure 2.2(a) above, which showed the region of parameters for which a NCE exists, by adding isowelfare levels and

[13]Since there is no net flow in our symmetric equilibrium, tariffs do not depend on distance.

the TSO's budget constraint. The dashed concave and decreasing curves in the figure represent different isowelfare curves. To see why these isowelfare levels are decreasing, note that increasing (decreasing) a tariff has a negative (positive) effect on social welfare. Therefore, to keep welfare constant, a rise in one tariff has to be accompanied by a fall in the other tariff. Since social welfare decreases in tariffs, isowelfare levels increase as we move from the northeast of the (t_{12}, t_{21}) space to the southwest. The solid convex and decreasing curve represents the TSO's budget constraint. This curve is decreasing since a lowering of one tariff must be met by an increase in the other tariff to keep the budget in balance. The problem of the TSO consists of picking the point on the budget constraint that yields the highest social welfare and therefore, at the optimum the isowelfare curve is tangent to the budget constraint. Moreover, observe that this point lies above $K = K_1(\cdot)$ and below $K = K_2(\cdot)$ so that for tariffs (t^*_{12}, t^*_{21}) the equilibrium without congestion exists.

Now the question becomes how these transportation tariffs relate to tariffs that would be set if there were full competition in both nodes. From Cremer and Laffont (2002), we know that the second-best nodal prices are implicitly given by the difference in the consumer price and the producer price. With the demand and cost structure chosen in this chapter, nodal prices are then given by

$$t^N_{12} = t^N_{21} = p^d_1 - c = \frac{C_K}{(a-c)^2},$$

where p^d_1 is the consumer price in node 1. Comparing these nodal prices with the tariffs stated in Proposition 2.2 shows that if producers have market power, nodal prices are too low to cover the cost of the TSO. The reason for this is that under imperfect competition aggregate output is lower than under perfect competition, which also means that the tax base is lower. Therefore, the TSO has to increase tariffs to be able to meet the break-even constraint. Figure 2.4 illustrates the difference between nodal prices and the tariffs in Proposition 2.2. Observe that t^N_{ij} and t^*_{ij} diverge when C_K increases and that both prices are equal to each other only when $C_K = 0$.

Profit-maximizing tariffs

Until now, we have assumed that the TSO acts as a benevolent social planner and thus implements transportation tariffs that maximize social welfare. Recently, however, there have been some attempts to privatize network operators. Therefore, it is useful to compare socially optimal tariffs with tariffs set by a profit-maximizing TSO. Notice that the solution of the gas market subgame still holds, so we only have

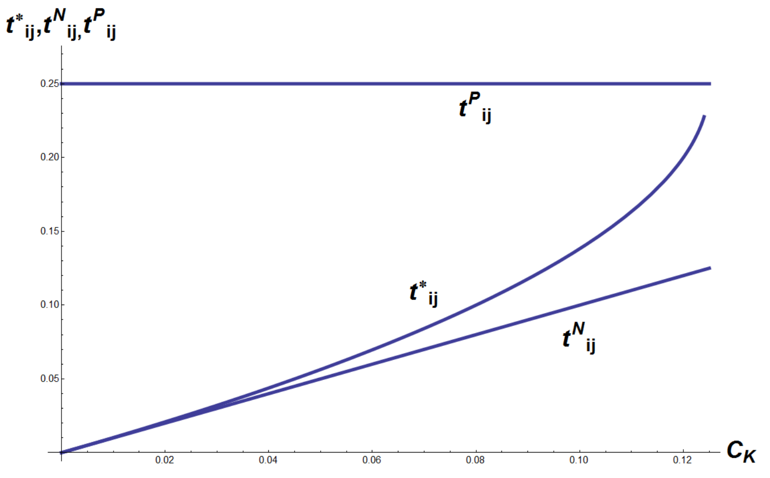


Figure 2.4: second-best tariffs and nodal prices $(a = 2, c = 1)$

to focus on the first stage of the game. The problem of the profit-maximizing TSO is then given by

$$\max_{(t_{12},t_{21})\in Z_{NC}} \{\pi^P = \frac{a-c-2t_{12}}{2} t_{12} + \frac{a-c-2t_{21}}{2} t_{21} - C_O(\cdot)\}.$$

The following result describes the solution to this problem.

Proposition 2.3 *Consider the set of tariff combinations*

$$T_{NC} \equiv \{(t_{12}, t_{21}) \in R^2 : (a, c, t_{12}, t_{21}, K) \in Z_{NC}\}.$$

Then t^P_{12} *and* t^P_{21} *denote the tariffs that generate the highest profit in this set, where*

$$t^P_{12} = t^P_{21} = \begin{cases} \frac{a-c}{4} & \text{if } K \geq \left(1 - \sqrt{11}/4\right)(a-c) \\ \frac{1}{6}(a-c) - \frac{1}{3}\sqrt{3K^2 + (a-c)^2 - 6(a-c)K} & \text{otherwise.} \end{cases}$$

The proof is in the Appendix.

Comparing these tariffs with the tariffs set by a benevolent but budget-constrained planner, given by Equation (2.15), one observes that profit-maximizing tariffs are excessive in terms of social welfare.

2.4 Congested pipeline

We now examine whether there are strategies that yield an equilibrium with congestion. We notice that the discussion on the equilibrium strategies of the last two stages in the previous section also applies here. So, there will be congestion in equilibrium only if firms' bookings violate the capacity constraint. After we have described the gas market equilibrium with congestion, we determine the second-best tariffs for this equilibrium.

2.4.1 Equilibria in the gas market

Let us turn to the question whether strategies b_{12} and b_{21} satisfying $|b_{21} - b_{12}| \geq K$ can be part of an equilibrium. Notice that if this were true, at the resulting equilibrium the pipeline would be congested. To start with, consider first a booking strategy profile such that $b_{12} \leq b_{21} - K$ (northwest of Figure 2.1), which implies that firm 2 will be rationed and obtain transmission rights $\bar{b}_{21} = b_{12} + K$. The second-stage profits of firm 1 equal

$$\pi_1(\cdot) = \left(\frac{a - b_{12} - K - c}{2}\right)^2 + \left(\frac{a - b_{12} - c}{2} - t_{12}\right) b_{12},$$

where we have substituted $q_{21} = \bar{b}_{21} = b_{12} + K$. Note that this profit expression is equal to the deviating profits expression we derived above in (2.7). The optimal booking of firm 1 is therefore given by

$$\widehat{b}_{12} = \begin{cases} K - 2t_{12} & \text{if } t_{12} \leq K/2 \\ 0 & \text{otherwise.} \end{cases} \tag{2.16}$$

Note that charging firm 1 a tariff higher than $t_{12} = K/2$ is (weakly) dominated, as it does not increase total output or relaxes the budget constraint compared to setting $t_{12} = K/2$. In the remainder of this section, we therefore only consider $t_{12} \leq K/2$.

Consider now the profits of firm 2. If the two producers' bookings satisfied $b_{12} \leq b_{21} - K$, firm 2 would obtain a level of profits given by the expression

$$\pi_2 = \left(\frac{a - b_{12} - K - c}{2} - t_{12}\right)(b_{12} + K) + \left(\frac{a - b_{12} - c}{2}\right)^2.$$

Observe that the profits of firm 2 do not depend on its own booking b_{21} but on the rival's booking b_{12}. As a result, any booking strategy that satisfies $b_{21} \geq \widehat{b}_{12} + K$ is consistent with equilibrium. Therefore, any booking

$$\widehat{b}_{21} \geq x \equiv 2K - 2t_{12} \tag{2.17}$$

is an equilibrium strategy for firm 2.

If the strategies in Equations (2.16) and (2.17) were part of an equilibrium, the aggregate market outcomes would be given by

$$\widehat{Q}_1 = \frac{1}{2}(a - c) + K - t_{12} \tag{2.18}$$

$$\widehat{p}_1 = \frac{1}{2}(a+c) + t_{12} - K \tag{2.19}$$

for market 1, and

$$\widehat{Q}_2 = \frac{1}{2}(a-c) + \frac{1}{2}K - t_{12} \tag{2.20}$$

$$\widehat{p}_2 = \frac{1}{2}(a+c) + t_{12} - \frac{1}{2}K \tag{2.21}$$

for market 2. Furthermore, profits of firm 1 and firm 2 would, respectively, be equal to

$$\widehat{\pi}_1 = \frac{1}{4}(a-c-K)^2 + \left(\frac{K}{2} - t_{12}\right)^2 \tag{2.22}$$

and

$$\widehat{\pi}_2 = \frac{(a-c)^2}{4} + \frac{(a-c)K}{2} + 2(t_{12}-K)t_{21} + 3t_{12}K - \frac{7K^2}{4} - t_{12}^2. \tag{2.23}$$

To see whether the strategies in Equations (2.16) and (2.17) are in fact part of an equilibrium, we have to find conditions under which neither firm has an incentive to deviate. For convenience, let us first check when firm 2 does not have an incentive to deviate. Consider firm 2 deviates by booking an amount b_{21}^d. We start by noting that a deviation by firm 2 can only be profitable if $b_{21}^d < \widehat{b}_{21}$. Indeed, as mentioned above, we can ignore upward deviations since all booking strategies $b_{21} > \widehat{b}_{21} \geq \widehat{b}_{12}+K$ yield the same profit to firm 2. We next observe that any deviation $b_{21}^d \in [\widehat{b}_{12}-K, \widehat{b}_{12}+K)$ cannot be profitable either. This is because this deviation results in a lowering of firm 2's exports to market 1 and it does not constrain firm 1's exports in any way.[14]

These two observations imply that, if a deviation is profitable for firm 2, it must be the case that $b_{21}^d \in [0, \widehat{b}_{12} - K)$, or, using (2.16), $b_{21}^d \in [0, -2t_{12})$. Note that such a deviation, which is only possible for negative t_{12}, changes the direction of the net flow and leads to a situation where firm 1 is rationed. If deviating is possible, the best deviation b_{21}^d solves

$$\max_{b_{21}^d \in [0,-2t_{12})} \{\pi_2^d = -\left(\frac{a - b_{21}^d - c}{2} - t_{21}\right) b_{21}^d + \left(\frac{a - b_{21}^d - K - c}{2}\right)^2\}. \tag{2.24}$$

Taking the first order condition yields

$$\frac{\partial \pi_2^d}{\partial b_{21}^d} = -\frac{b_{21}^d}{2} + \frac{K}{2} - t_{21},$$

which shows that deviating profits in Equation (2.24) are monotonically decreasing in b_{21}^d when $t_{21} \leq K/2 + t_{12}$ so no profitable deviation exists in that case. For other

[14]Note that profits of firm 2 are concave in q_{21}, so that its profits are increasing in q_{21} for all $q_{21} \leq q_{21}^*$.

ranges of t_{21}, we get that deviation profits are maximized when

$$b_{21}^d = \begin{cases} K - 2t_{21} & \text{if } K/2 + t_{12} < t_{21} < K/2 \\ 0 & \text{if } t_{21} \geq K/2. \end{cases} \tag{2.25}$$

Substituting (2.25) into (2.24) yields the optimal deviating profits:

$$\pi_2^d = \begin{cases} \frac{1}{4}(a-c-K)^2 + \left(\frac{K}{2} - t_{21}\right)^2 & \text{if } K/2 + t_{12} < t_{21} < K/2 \\ \\ \frac{1}{4}(a-c-K)^2 & \text{if } t_{21} \geq K/2. \end{cases} \tag{2.26}$$

Comparing (2.23) and (2.26), we conclude that firm 2 does not have an incentive to deviate whenever

$$\widehat{\pi}_2(\widehat{b}_{12}, \widehat{b}_{21}) \geq \pi_2^d(\widehat{b}_{12}, b_{21}^d) \Leftrightarrow K \geq \widehat{K}_2(a, c, t_{12}, t_{21}),$$

where

$\widehat{K}_2(\cdot) \equiv$

$$\begin{cases} 0 & \text{if } t_{12} \geq t_{21} \\ \frac{2}{9}\left(a-c+3t_{12}-t_{21}-\sqrt{(a-c+6t_{12}-4t_{21})(a-c+2t_{21})}\right) & \text{if } 4t_{21}-\sqrt{2t_{21}(a-c+2t_{21})}<t_{12}<t_{21} \\ \frac{1}{4}\left(a-c+3t_{12}-2t_{21}-\sqrt{(a-c)^2+(6t_{12}-4t_{21})(a-c)+(t_{12}+2t_{21})^2}\right) & \text{if } t_{12} \leq 4t_{21}-\sqrt{2t_{21}(a-c+2t_{21})}. \end{cases}$$

Next, consider a deviation by firm 1 and let b_{12}^d denote its defection from the equilibrium strategy in (2.16). Since the equilibrium booking is the maximizer of the profits of firm 1 when $b_{12} \leq \widehat{b}_{21} - K$, a deviating booking can only be profitable if it decongests the pipeline, i.e. if $b_{12}^d > \widehat{b}_{21} - K$. Under such a deviation, firm 2 is not rationed any longer and is allocated transmission rights equal to $\widehat{b}_{21}$. Note furthermore that if firm 1 deviates by booking $b_{12}^d > \widehat{b}_{21} + K$, it will be rationed by the TSO. The deviant thus solves the following constrained maximization problem:

$$\max_{b_{12}^d \in [0, \widehat{b}_{21}+K)} \{\pi_1^d = (a - \widehat{b}_{21} - BR(\widehat{b}_{21}) - c)BR(\widehat{b}_{21}) + (a - b_{12}^d - BR(b_{12}^d) - c - t_{12})b_{12}^d\}.$$

It is readily seen that the optimal deviation of firm 1 is

$$b_{12}^d = \min\{\widehat{b}_{21} + K, \frac{a-c}{2} - t_{12}\},$$

yielding profits equal to

$$\pi_1^d = \begin{cases} \left(\frac{a-\widehat{b}_{21}-c}{2}\right)^2 + \frac{(a-c-2t_{12})^2}{8} & \text{if } \frac{a-c}{2} - t_{12} \leq \widehat{b}_{21} + K \\ \left(\frac{a-\widehat{b}_{21}-c}{2}\right)^2 + \left(\frac{a-\widehat{b}_{21}-K-c}{2} - t_{12}\right)\left(\widehat{b}_{21} + K\right) & \text{otherwise.} \end{cases}$$

Therefore firm 1 does not deviate from playing the strategy given by (2.16) if

$$\widehat{\pi}_1(\widehat{b}_{12}, \widehat{b}_{21}) \geq \pi_1^d(b_{12}^d, \widehat{b}_{21}) \Leftrightarrow K \leq \widehat{K}_1(a, c, t_{12}, \widehat{b}_{21}),$$

where

$$\widehat{K}_1(\cdot) \equiv \begin{cases} \left(\frac{1}{2}-\frac{1}{\sqrt{2}}\right)(a-c)+t_{12}+\frac{\widehat{b}_{21}}{\sqrt{2}} & \text{if } t_{12} \geq \frac{1}{2}\left(\frac{a-c-\widehat{b}_{21}}{\sqrt{2}}-\widehat{b}_{21}\right) \\ \frac{1}{2}\left(a-c-\widehat{b}_{21}-\sqrt{(a-c-2\widehat{b}_{21})(a-c)-4(\widehat{b}_{21}+t_{12})t_{12}}\right) & \text{otherwise.} \end{cases} \quad (2.27)$$

Having derived the conditions under which no firm deviates from the strategies in Equations (2.16) and (2.17), we are now ready to state our second equilibrium result. For this purpose, let us define the following set of parameters:

$$Z_C(x) \equiv \{(a, c, t_{12}, t_{21}, K) : K \leq \widehat{K}_1(a, c, t_{12}, x);\ K \geq \widehat{K}_2(\cdot)\}.$$

The next proposition summarizes our second equilibrium result.

Proposition 2.4 *For any vector of parameters $(a, c, t_{12}, t_{21}, K) \in Z_C(x)$ there exists a continuum of gas market equilibria where firms' pipeline capacity bookings $(\widehat{b}_{12}, \widehat{b}_{21})$ satisfy (2.16) and (2.17) respectively, transmission rights allocated are given by (2.2) and production levels are stated in (2.1). In any equilibrium, bookings are such that the network is congested and firm 2 is rationed.*

Proposition 2.4 tells us that for some pipeline capacity and transportation prices, there exists an equilibrium in which firm 1 lowers its request for capacity such that the pipeline becomes congested. Firm 2 is then rationed, while the net flow is in the direction of node 1. Although it loses some profits from exporting, firm 1 gains local market power in this way since firm 2 cannot export as much as it wants to. Whether this gain outweighs the loss from lower exports depends on pipeline capacity and tariffs, as is discussed below.[15]

To illustrate further Proposition 2.4 we need to resolve somehow the indeterminacy of equilibria. In what follows we shall consider that $\widehat{b}_{21} = \dfrac{a-c}{2} - t_{21}$; arguably, this booking may be a natural focal point since it is the amount that firms would book in an equilibrium with no congestion.[16] Substituting this value for $\widehat{b}_{21}$ into (2.27), this yields

[15] This result is related to the study in Borenstein, Bushnell and Stoft (2000), who show that when capacity of the power network is small there does not exist an equilibrium without congestion.

[16] Indeed, since during the summer season there is typically no congestion in most markets while the opposite holds for the winter season, one may argue that summer bookings maybe natural bookings for the winter season in this case of indeterminacy. In addition, we note that $\widehat{b}_{21} = \frac{a-c}{2} - t_{21}$ is an equilibrium booking for firm 2 as long as $\frac{a-c}{2} - t_{21} \geq 2K - 2t_{12}$, which in equilibrium indeed holds.

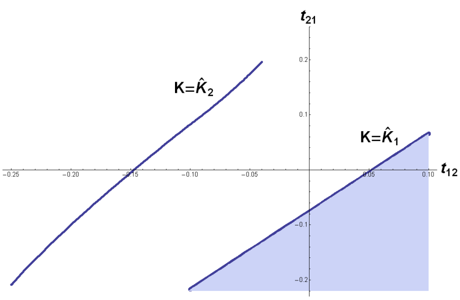
$$\widehat{K}_1(\cdot) = \begin{cases} \left(1-\frac{1}{\sqrt{2}}\right)\frac{a-c}{2} + t_{12} - \frac{t_{21}}{\sqrt{2}} & \text{if } t_{12} \geq B(t_{21}) \\ \frac{1}{4}\left(a-c+2t_{21} - 2\sqrt{2}\sqrt{(a-c+2t_{12})(t_{21}-t_{12})}\right) & \text{otherwise,} \end{cases} \tag{2.28}$$

where

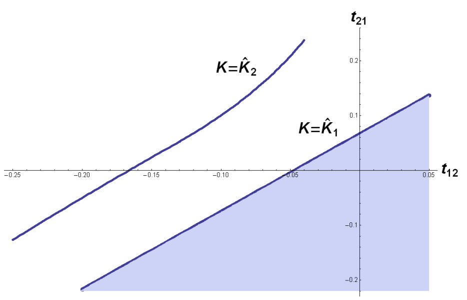
$$B(t_{21}) \equiv \left(\frac{1}{\sqrt{2}} - 1\right)\frac{a-c}{4} + \left(1+\frac{1}{\sqrt{2}}\right)\frac{t_{21}}{2}.$$

Figures 2.5(a) and 2.5(b), drawn for $\widehat{b}_{21} = \dfrac{a-c}{2} - t_{21}$, show the regions of parameters for which equilibrium described in Proposition 2.4 exists. Again, the left (right) figure corresponds to the case of large (small) capacity. All combinations of tariffs that lie below the two bounds lead to the congested equilibrium.

Some intuition can be gained if one considers the incentives for firm 1 to deviate from the equilibrium strategy. If t_{12} is relatively high, exporting, and therefore also deviating from equilibrium, becomes less attractive. Further, a relatively low t_{21} makes a defection less beneficial, because in that case firm 2 would export a large amount to market 1. In regard to the deviating incentives for firm 2, observe that firm 2 also has no incentive to deviate from the equilibrium strategy if t_{12} is high and t_{21} is low, but for different reasons than firm 1. First, a deviation is not profitable for firm 2 when t_{12} is high. If this is the case, the exports of firm 1 are low and firm 2 does not gain much by changing the direction of the flow while it loses a lot due to the reduction in exports. Moreover, firm 2 does not deviate if t_{21} is low, since a low t_{21} makes it more profitable for firm 2 to export a large amount.



(a) Large pipeline capacity ($K = 0.2$)



(b) Small pipeline capacity ($K = 0.1$)

Figure 2.5: Shaded areas: parameters for which an equilibrium with congestion exists ($a = 2; c = 1$)

Finally, comparing Figures 2.5(a) and 2.5(b) one sees that when pipeline capacity is small the set of tariffs for which the congested equilibrium of Proposition 2.4

exists is larger. To see why this is true, note that firm 2 can only export an amount $\bar{b}_{21} = b_{12} + K$ if it is rationed. Then, it is more often beneficial for firm 1 to provoke congestion in case of small capacity since the exports of firm 2 remain low no matter what.

In order to complete the analysis in this section, we need to examine booking strategy profiles satisfying $b_{21} \leq b_{12} - K$ (southeast of Figure 2.1). These strategy profiles lead to a situation where firm 1 will be rationed and obtain transmission rights $\bar{b}_{12} = b_{21} + K$. This case is similar to the case analyzed above in detail so, to save space, we do not present the derivations. The equilibria in which firm 1 is rationed exist when t_{12} is relatively low and t_{21} is relatively high.

2.4.2 Transportation pricing

We have shown in Proposition 2.2 that the pair of tariffs (t_{12}^*, t_{21}^*) is socially optimal if the pipeline is not congested. Note however that if pipeline is relatively small, setting these tariffs does not lead to an equilibrium without congestion. It also holds that in such a case, no other pair of tariffs satisfies both $K \geq \max\{K_1(\cdot), K_2(\cdot)\}$ and the budget constraint, which implies that the pipeline will be congested in the ensuing equilibrium. If this is so, it is no longer necessarily true that (t_{12}^*, t_{21}^*) are (constrained) welfare-maximizing.

Second-best tariffs

We now analyze the second-best transportation tariffs when firms' strategies in the continuation game lead to the congested equilibrium (CE) of Proposition 2.4, i.e. where firm 1 lowers its exports and firm 2 is rationed (the analysis is similar for the symmetric case where firm 1 is rationed instead). For fixed a, c, K, the TSO solves the following constrained maximization problem:

$$\max_{(t_{12},t_{21})\in Z_C(\cdot)} \quad \{SW = \int_0^{\widehat{Q}_1(t_{12})} \Big(a - x - c\Big)dx + \int_0^{\widehat{Q}_2(t_{12})} \Big(a - x - c\Big)dx - C_O(\cdot)\},$$

subject to:

$$t_{12}\widehat{q}_{12}(t_{12}) + t_{21}\widehat{q}_{21}(t_{12}) - C_O(\cdot) = 0. \tag{2.29}$$

This leads to the following result.

Proposition 2.5 *For fixed a, c, K, c_O, C_K, consider the set $T_C(a, c, K, c_O, C_K)$ of TSO's-budget-constraint-satisfying pairs of tariffs that result in firms playing strategies that lead to the equilibrium with congestion of Proposition 2.4:*

$$T_C(a, c, K, c_O, C_K) \equiv \{(t_{12}, t_{21}) \in R^2 : (t_{12}, t_{21}) \in Z_C(\cdot); \sum t_{ij}\widehat{q}_{ij} \geq C_O\},$$

with $\widehat{q}_{ij}$ given in Proposition 2.4. If this set is non-empty, the element $(\widehat{t}_{12}, \widehat{t}_{21})$ that solves the system of equations

$$t_{12}\widehat{q}_{12}(t_{12}) + t_{21}\widehat{q}_{21}(t_{12}) - C_O(\cdot) = 0 \tag{2.30}$$

$$K - \widehat{K}_1(a, c, t_{12}, t_{21}) = 0 \tag{2.31}$$

yields the highest welfare.

The proof is in the Appendix.

Figure 2.6, which builds on Figure 2.5 above by adding isowelfare curves and the TSO's budget constraint, illustrates Proposition 2.5. Notice that the isowelfare curves are vertical and that welfare increases as we lower the tariff on firm 1's exports. As a result, welfare is maximized at the point where the line representing $K = K_1(\cdot)$ and the curve representing the budget constraint (BC) intersect. Observe that $\widehat{t}_{12} < 0$ and $\widehat{t}_{21} > 0$, so that the dominant flow is taxed while the reverse flow is subsidized.

In contrast to the situation described in Proposition 2.2 where firms play strategies that lead to no congestion, if the pipeline is congested optimal transportation prices are not equal to each other. More specifically, the dominant flow (firm 2's exports) is taxed while the reverse flow (firm 1's exports) is subsidized. As firm 2 does not respond to changes in tariffs when it is rationed, a raise in t_{21} has no effect on welfare. However, by increasing t_{21} the TSO generates more revenue coming from firm 2 thereby relaxing the budget constraint. This enables the TSO to lower t_{12}, which has a positive effect on aggregate output on both markets so that total welfare goes up. This cross-subsidization is in line with the principles of Ramsey-Boiteaux pricing, as the firm with the lower export elasticity (with respect to the transportation tariff) is taxed more heavily.

To compare the pair of tariffs $(\widehat{t}_{12}, \widehat{t}_{21})$ with nodal prices, for simplicity we focus on the case where $C_K = 0$. Since under nodal pricing we would get $t_{12}^N = -t_{21}^N$ while we have $\widehat{t}_{12} \neq -\widehat{t}_{21}$, it is clear that $(\widehat{t}_{12}, \widehat{t}_{21})$ are not equal to nodal prices.

2.5 Subgame perfect equilibrium

We have derived the second-best tariffs in two cases, the case where firms equilibrium strategies lead to no congestion (Proposition 2.2) and the case where firms strategies lead to pipeline congestion and firm 2 is rationed (Proposition 2.5). The case where firm 1 is rationed is similar and has been omitted to save space. We also know that if for the tariffs (t_{12}^*, t_{21}^*) given in Proposition 2.2 an equilibrium without congestion

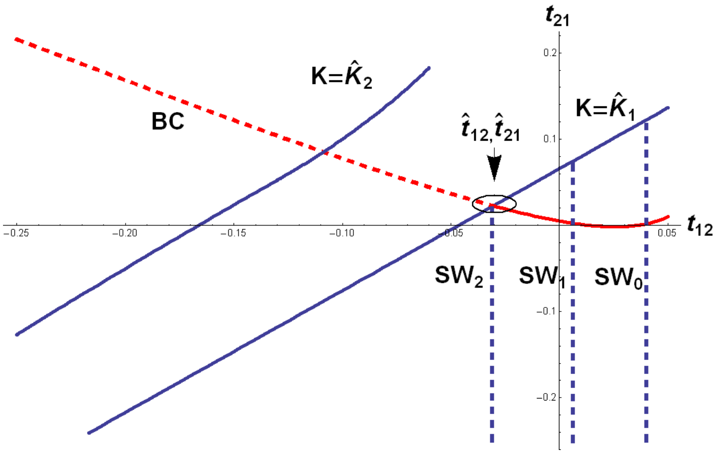


Figure 2.6: Optimal tariffs in equilibrium with congestion ($a = 2, c = 1, K = 0.2, c_O = 0.01, C_K = 0$)

does not exist, then no other budget constraint satisfying tariffs exist such that firms play the NCE (see the proof of Proposition 2.2).

We now ask whether the level of welfare attained when the TSO sets (t^*_{12}, t^*_{21}) and firms play the NCE of Proposition 2.1 is higher or lower than in case the TSO sets $(\widehat{t}_{12}, \widehat{t}_{21})$ and firms play the CE of Proposition 2.4.

Lemma 2.1 *For fixed parameters (K, c, c_O, C_K) such that $T_{NC}(\cdot) \neq \emptyset$ and $T_C(\cdot) \neq \emptyset$,*

$$SW_{NCE}(t^*_{12}, t^*_{21}) > SW_{CE}(\widehat{t}_{12}, \widehat{t}_{21}),$$

where SW_{NCE} and SW_{CE} are the levels of social welfare in the equilibrium without congestion and the equilibrium with congestion, respectively.

The proof is in the Appendix.

Lemma 2.1 shows that when the TSO can choose among the transportation tariffs that lead to the equilibrium without congestion and the tariffs that yield the equilibrium with congestion, then he prefers the symmetric equilibrium with no congestion. This remark allows us to state our final result in this section.

Proposition 2.6 *For fixed parameters (a, c, K, c_O, C_K), we can distinguish two cases:*

(i) $(t^*_{12}, t^*_{21}) \in Z_{NC}(\cdot)$, in which case the (unique) SPE of the game is as follows: the TSO sets transportation tariffs $t^*_{12} = t^*_{21}$ given in (2.15), firms' exports are equal to the bookings and market outcomes are given by (2.4) and (2.5).

(ii) $(t^*_{12}, t^*_{21}) \notin Z_{NC}(\cdot)$*, in which case there are two SPE with congestion. In one equilibrium, optimal tariffs are given by the solutions to (2.30) and (2.31), firm 1 provokes congestion, firm 2 is rationed and market outcomes are given by (2.18),(2.19),(2.20), and (2.21). The other equilibrium is the mirror of this SPE.*

2.6 Asymmetric markets

We now study optimal transportation tariffs when markets are asymmetric and pipeline capacity is sufficiently large, so that firms do not have an incentive to congest the line. Suppose that the inverse demand function for node 1 equals

$$P_1(Q_1) = 1 - Q_1,$$

while inverse demand for node 2 is given by

$$P_2(Q_2) = \frac{1}{b}\left(1 - \frac{Q_2}{M}\right),$$

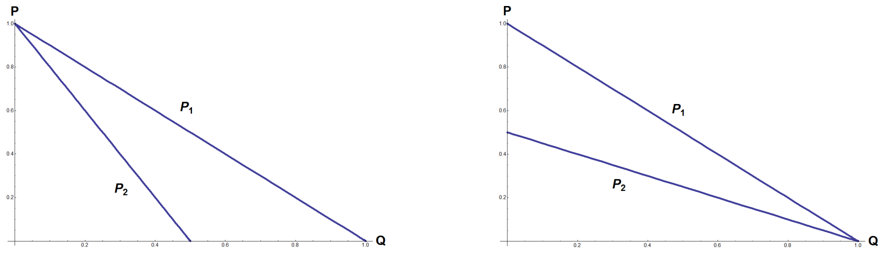
where we assume that $b \geq 1$ and $M \in (0, 1]$. The parameters b and M respectively reflect the willingness to pay of consumers in market 2 relative to the willingness to pay of consumers in market 1 and the relative size of market 2.[17] We can vary b and M to get different kinds of asymmetries between the two markets. Consider for example the case where $b = 1$ and $M = 0.5$. Then the willingness to pay is the same across nodes, but market 1 is twice as big as market 2 in terms of consumer mass.

Figure 2.7(a), illustrating the inverse demand functions for this market asymmetry, shows that for a given price demand in market 1 is higher than in market 2 (except for the reservation price $p_i = 1$). However, demand in both nodes converge as the price increases. Another kind of asymmetry arises when the consumers' willingness to pay differs across markets. Figure 2.7(b) graphs the inverse demand functions for the case where $b = 2$ and $M = 1$. Again, for a given price the demand is higher in market 1 than in market 2 but now demand in both markets come closer as the price goes down.

Assuming that the net flow is in the direction of node 1, the first best tariffs for the asymmetric market case are given by

$$\begin{aligned} t_{12} &= -\frac{1/b - c}{2} - 4c_O \\ t_{21} &= -\frac{1 - c}{2} + 4c_O. \end{aligned}$$

[17]Notice that a high value of b implies a low willingness to pay of market 2 consumers and that a high value of M means a relatively big market 2.



(a) $P_1 = 1 - Q_1$; $P_2 = 1 - 2Q_2$ (b) $P_1 = 1 - Q_1$; $P_2 = 1/2(1 - Q_2)$

Figure 2.7: Two different kinds of market asymmetries

The second-best tariffs are then equal to

$$\begin{aligned} t_{12} &= \frac{4\lambda(M) - 1}{16\lambda(M) + 2}(1/b - c) - \frac{4(1 + \lambda(M))}{8\lambda(M) + 1}c_O \\ t_{21} &= \frac{4\lambda(M) - 1}{16\lambda(M) + 2}(1 - c) + \frac{4(1 + \lambda(M))}{8\lambda(M) + 1}c_O, \end{aligned}$$

where $\lambda(M) > 1/4$ is the shadow price of the constrained optimization problem.

We first notice that first-best transportation tariffs are symmetric only when the willingness to pay is the same across markets and the cost of shipping equals zero. In any other case, the tariff charged to firm 2 is higher than the tariff charged to firm 1 since (i) in this way the (cost of the) net flow becomes smaller and/or (ii) the willingness to pay is greater in node 1 than in node 2.

Next, note that the second-best tariffs have the same shape as the first-best tariffs, although the former are higher due to the (binding) budget constraint. To obtain a closed-form solution for the second-best tariffs, suppose that $c_O = 0$ and $b = 1$. In this case, the markets only differ with respect to size and the cost of the TSO to ship gas is zero.[18] The second-best transportation prices are then as follows:

$$t_{12} = t_{21} = \frac{a - c - \sqrt{(a-c)^2 - \frac{16}{1+M}C_K}}{4}.$$

Interestingly, although the markets still differ in size, optimal tariffs are now symmetric. Moreover, an increase in the market size of market 2, resulting in a larger tax base, leads to a reduction in the tariff for the dominant flow as well as for the reverse flow.

[18]The case considered here may not be an unrealistic one, since consumers within different but geographically close regions most likely have a similar willingness to pay for gas and moreover, the TSO's cost of shipping the gas is typically rather small relative to the fixed cost the TSO bears.

2.7 Conclusion

We have studied the role of transportation pricing in shaping the incentives of gas suppliers with market power. The model has considered a setting where two firms serve two distant markets connected by a pipeline, which is under control of a regulated TSO. Each producer is located at one of the ends of the pipeline and chooses gas supplies for the local and for the distant market.

Abstracting from any friction between the regulator and the TSO, the first-best solution calls for subsidies so as to induce producers to export the competitive quantity. However, such a transportation pricing system would lead to significant losses for the TSO. To circumvent this problem, we have studied tariffs that satisfy the TSO's budget constraint.

Which transportation prices maximize welfare depends on pipeline capacity, and indirectly on the profit-maximizing strategies of the firms. When capacity of the pipeline is sufficiently large, neither firm has an incentive to deliberately congest the line and the second-best tariffs are the lowest ones that satisfy the budget constraint. When markets are similar, these tariffs are symmetric so the optimal transportation pricing system is non-discriminatory.

Yet, in case pipeline capacity is relatively small one of the gas suppliers has an incentive to lower its exports thereby provoking congestion in the transportation system. In this situation, the TSO finds it optimal to subsidize the such firm so as to weaken the distortions arising from congestion. To balance budget, the TSO charges the rival firm a strictly positive tariff. Therefore, with small pipeline capacity firms do not pay the same transportation tariffs and the optimal pricing system is discriminatory. Moreover, it follows the principles of Ramsey-Boiteaux pricing: the firm with the lowest supply elasticity faces the highest price for shipping its gas. These results on optimal transportation pricing show that when gas production is not competitive, socially optimal tariffs differ from transportation prices based on nodal pricing principles.

The chapter has also presented a comparison of transportation prices that maximize the profits of the TSO with second-best transportation tariffs. Profit-maximizing prices are excessive from the point of view of social welfare maximization. As usual, when the TSO chooses tariffs to maximize its own profits, it does not take into account how tariffs influence consumer's surplus and the profits of the gas suppliers.

2.A Appendix

Proof of Proposition 2.2. We start by showing that $t_{12}^* = t_{21}^*$. As a first observation, note that the net flow in the NCE is zero if tariffs are equal to each other. In contrast, when tariffs are not the same the TSO deals with a positive net flow. Therefore, if optimal tariffs are symmetric in case $c_O = 0$ we know for sure that symmetry also holds in situations where the TSO incurs a cost of shipping the gas. We thus only have to prove for the case $c_O = 0$.

The FOC's that yield the solution for this case are as follows:

$$-\frac{1}{2}(a - Q_1^* - c) + \lambda\left(\frac{a - c - 4t_{21}}{2}\right) - \mu = 0$$
$$-\frac{1}{2}(a - Q_2^* - c) + \lambda\left(\frac{a - c - 4t_{12}}{2}\right) + \mu = 0,$$

where λ and μ are the multipliers for the TSO's budget constraint and the condition $t_{12} \geq t_{21}$, respectively. Suppose now that the latter constraint does not bind; we then get $\mu = 0$ and

$$\frac{a - Q_1^* - c}{a - Q_2^* - c} = \frac{a - c - 4t_{21}}{a - c - 4t_{12}}.$$

But the left hand side is smaller than one (since $Q_1^* > Q_2^*$) while the right hand side is larger than one, hence a contradiction. Therefore, the condition $t_{12} \geq t_{21}$ binds and optimal tariffs are symmetric.

We are now able to obtain exact expressions for the transportation prices. Since $t_{21} = t_{12}$, the net flow is zero and tariffs thus have to solve

$$2t_{12}q_{12}^* = C_K,$$

where we have substituted $t_{21} = t_{12}$. Solving for t_{12} gives the optimal transportation tariffs stated in Proposition 2.2.

As a final step, we prove that $T_{NC} = \emptyset$ if $(t_{12}^*, t_{21}^*) \notin T_{NC}$. First we show that when $(t_{12}^*, t_{21}^*) \notin T_{NC}$, no pair of asymmetric tariffs is in this set. Note that (t_{12}^*, t_{21}^*) is not in T_{NC} only if this combination does not yield the equilibrium without congestion, or if $(a, c, t_{12}, t_{21}, K) \notin Z_{NC}$. Hence, the vector of parameters $(a, c, t_{12}, t_{21}, K)$ is such that $K < \max\{K_1(\cdot), K_2(\cdot)\}$. But since $t_{12}^* = t_{21}^*$ and $K_2(\cdot)$ is just the mirror of $K_1(\cdot)$, we get $K < K_1(a, c, t_{12}^*, t_{21}^*) = K_2(a, c, t_{12}^*, t_{21}^*)$. Now it is easy to see that there is no pair of asymmetric tariffs included in the set. One could for example lower t_{12} such that $K \geq K_1(\cdot)$, but an increase of t_{21} is then required to again satisfy the budget constraint. This leads to an increase in $K_2(\cdot)$, so $K < K_2(\cdot)$ still holds. We still have to show that there are no other pairs of symmetric tariffs in the set.

Clearly, lower symmetric tariffs violate the budget constraint and higher symmetric tariffs increase the critical values $K_1(\cdot)$ and $K_2(\cdot)$. Therefore, any combination of symmetric tariffs for which holds that tariffs are higher or lower than (t^*_{12}, t^*_{21}) are not in T_{NC} if the pair (t^*_{12}, t^*_{21}) itself is not in this set. ∎

Proof of Proposition 2.3. Again, we have that optimal tariffs are equal to each other (which is shown below) so that it is sufficient to restrict the analysis to the case $c_O = 0$. Suppose that the constraint does not bind; from the FOCs we get that the profit-maximizing tariffs are given by the interior solution $t^P_{12} = t^P_{21} = \dfrac{a-c}{4}$. If, in contrast, the constraint is binding, we have that tariffs $t^P_{12} = t^P_{21}$ solve $K = K_1(\cdot) = K_2(\cdot)$, a corner solution. To see that the corner solution also yields tariffs being equal to each other, suppose, without loss of generality, that $t_{12} \leq t_{21}$ which implies that $K_1(\cdot) \leq K_2(\cdot)$. Clearly, $K_1(\cdot) \leq K_2(\cdot) < K$ cannot be profit-maximizing because the TSO can raise t_{21} without violating the constraint, thereby increasing its profits. We therefore must have that $K_1(\cdot) \leq K_2(\cdot) = K$. Suppose now that $t_{12} < t_{21}$ so that $K_1(\cdot) < K_2(\cdot) = K$. But then one can gain by increasing t_{12} such that constraint is still satisfied. As a result, $t_{12} = t_{21}$ and $K = K_1(\cdot) = K_2(\cdot)$. Since the TSO wants to set tariffs as high as possible (provided that for the corner solution it holds that $t_{12} = t_{21} < (a-c)/4$), the second part of (2.10) applies. Respecting that $t_{12} = t_{21}$ and rewriting a bit gives the corner solution stated in Proposition 2.3. ∎

Proof of Proposition 2.5. First observe from Equation (2.29) that welfare in the CE (i) is constant in t_{21} and (ii) is decreasing (constant) in t_{12} for $t_{12} < K/2$ $(t_{12} \geq K/2)$. Therefore, the TSO wants to set t_{12} as low as possible without violating the constraints stated in (2.29). We already know that at the optimum, the budget constraint binds. We complete this proof by showing that the condition $K = K_1(\cdot)$ also binds. First note that for $(a, c, t_{12}, t_{21}, K) \in Z_C(\cdot)$, we have $\widehat{K}_2(\cdot) \leq \widehat{K}_1(\cdot)$ so that $K \geq \widehat{K}_2(\cdot)$ is automatically satisfied if $K \leq \widehat{K}_1(\cdot)$ is binding. Suppose now by contradiction that the latter constraint does not bind, so $K < \widehat{K}_1(\cdot)$. But then we could gain in terms of social welfare by lowering t_{12} (and raising t_{21}) up to the point where the constraint becomes binding. Therefore, at the optimum the condition $K \leq K_1(\cdot)$ binds. ∎

Proof of Lemma 2.1. This proof consists of two steps. The first step is to show

$$SW_{NCE}(\widehat{t}_{12}, \widehat{t}_{21}) > SW_{CE}(\widehat{t}_{12}, \widehat{t}_{21}).$$

It is obvious that this inequality holds, since for equal tariffs output in each node (and therefore welfare) is higher in the NCE than in the CE.

Next, we have to prove that

$$SW_{NCE}(t_{12}^*, t_{21}^*) > SW_{NCE}(\widehat{t}_{12}, \widehat{t}_{21}).$$

To demonstrate that this condition is satisfied, we make use of the following Lemma.

Lemma 2.2 *The pair of tariffs* $(\widehat{t}_{12}, \widehat{t}_{21})$ *is in the choice set of the TSO if* $T_{NC}(\cdot) \neq \emptyset$.

Proof of Lemma 2.2 In order to prove Lemma 2.2, we have to establish that
a) $(\widehat{t}_{12}, \widehat{t}_{21}) \in Z_{NC}(\cdot)$ if $T_{NC}(\cdot) \neq \emptyset$ and
b) $BC_{NCE}(\widehat{t}_{12}, \widehat{t}_{21}) \geq 0$,
where $BC_{NCE}(\cdot)$ denotes the TSO's budget constraint in the NCE.

To show that *a*) holds, we first notice that $(\widehat{t}_{12}, \widehat{t}_{21})$ is such that the first part of Equation (2.28) always binds:

$$K = \left(1 - \frac{1}{\sqrt{2}}\right)\frac{a-c}{2} + \widehat{t}_{12} - \frac{\widehat{t}_{21}}{\sqrt{2}}. \tag{2.32}$$

Suppose by contradiction that the second part of Equation (2.28) is the relevant bound, so

$$K = \frac{1}{4}\left(a - c + 2\widehat{t}_{21} - 2\sqrt{2}\sqrt{(a-c+2\widehat{t}_{12})(\widehat{t}_{21} - \widehat{t}_{12})}\right). \tag{2.33}$$

For a given K and $\widehat{t}_{12}$, the optimal t_{21} in the CE is then found by rewriting (2.33):

$$\widehat{t}_{21} = \frac{1}{2}\left(a - c + 4\left(K + \widehat{t}_{12} - \sqrt{(a-c+2\widehat{t}_{12})K}\right)\right). \tag{2.34}$$

Note that the second part of (2.28) applies when $t_{21} > t_{12} + K$, so (2.34) only holds when

$$\frac{1}{2}\left(a - c + 4\left(K + \widehat{t}_{12} - \sqrt{(a-c+2\widehat{t}_{12})K}\right)\right) > \widehat{t}_{12} + K,$$

or when

$$K \lessapprox 0.172\left(\frac{a-c}{2} + \widehat{t}_{12}\right) \vee K \gtrapprox 5.828\left(\frac{a-c}{2} + \widehat{t}_{12}\right).$$

Now, given that $T_{NC}(\cdot) \neq \emptyset$ and that in case of no congestion the lowest feasible second-best tariffs are $t_{12}^* = t_{21}^* = 0$, it is easy to see from Equation (2.10) that

$$K \geq \left(1 - \frac{1}{\sqrt{2}}\right) \frac{(a-c)}{2}. \tag{2.35}$$

Taking into account that $\widehat{t}_{12} \leq K/2$, (2.35) implies that

$$K \lessapprox 0.172 \left(\frac{a-c}{2} + \widehat{t}_{12}\right)$$

cannot be true. This means that (2.33) only holds when

$$K \gtrapprox 5.828 \left(\frac{a-c}{2} + \widehat{t}_{12}\right). \tag{2.36}$$

To see that this also cannot be the case, note that in the CE the TSO has to set $t_{12} = -(a-c)/2 + K/2$ to entice firm 1 to export the competitive output. This tells us that in the CE $\widehat{t}_{12} \geq -(a-c)/2 + K/2$. Then, straightforward calculation shows that (2.36) does not hold, implying that (2.32) is true.

Furthermore, given that $\widehat{t}_{12} \leq K/2$, we obtain that (2.10) and (2.28) coincide. This implies that $(\widehat{t}_{12}, \widehat{t}_{21}) \in Z_{NC}(\cdot)$ if $T_{NC}(\cdot) \neq \emptyset$.

For condition (b) to hold, we must have the TSO's budget constraint is satisfied when the pair of tariffs $(\widehat{t}_{12}, \widehat{t}_{21})$ is implemented and firms play strategies yielding the NCE. Substituting the equilibrium quantities gives

$$\widehat{t}_{12} q_{12}^*(\widehat{t}_{12}) + \widehat{t}_{21} q_{21}^*(\widehat{t}_{21}) - \left| q_{21}^*(\widehat{t}_{21}) - q_{12}^*(\widehat{t}_{12}) \right| c_O - C_K \geq 0.$$

To prove that this inequality holds, first notice that if the NCE with tariffs (t_{12}^*, t_{21}^*) exists, we have

$$K \geq K_1(a, c, t_{12}^*, t_{21}^*).$$

This implies that tariffs $(\widehat{t}_{12}, \widehat{t}_{21})$ satisfying $K = \widehat{K}_1(a, c, \widehat{t}_{12}, \widehat{t}_{21})$ have to be such that $\widehat{t}_{12} \geq \widehat{t}_{21}$, as can be seen from (2.10) and (2.28). Note moreover that these tariffs also have to satisfy the TSO's budget constraint in case of congestion, which is given by

$$\widehat{t}_{12} \widehat{q}_{12}(\widehat{t}_{12}) + \widehat{t}_{21} \widehat{q}_{21}(\widehat{t}_{21}) - K c_O - C_K = 0.$$

Since $\widehat{q}_{21}(\widehat{t}_{21}) > \widehat{q}_{12}(\widehat{t}_{12})$, we now also get that $\widehat{t}_{12} > |\widehat{t}_{21}|$. Now define, for given tariffs $\widehat{t}_{12}$ and $\widehat{t}_{21}$, the differences between quantities in the NCE and the CE as $\Delta_{12}(\widehat{t}_{12}) \equiv q_{12}^*(\widehat{t}_{12}) - \widehat{q}_{12}(\widehat{t}_{12})$ and $\Delta_{21}(\widehat{t}_{21}) \equiv q_{21}^*(\widehat{t}_{21}) - \widehat{q}_{12}(\widehat{t}_{21}) - K$. We then get

$$\Delta_{12}(\widehat{t}_{12}) - \Delta_{21}(\widehat{t}_{21}) = q_{12}^*(\widehat{t}_{12}) - q_{21}^*(\widehat{t}_{21}) + K > 0,$$

where the inequality follows from the fact that in the equilibrium without congestion the net flow is smaller than K. As a final step, we rewrite the $BC_{NCE}(\widehat{t}_{12}, \widehat{t}_{21})$ as follows:

$$\begin{aligned}
& \left(\widehat{t}_{12} + c_O\right)\left(\widehat{q}_{12}(\widehat{t}_{12}) + \Delta_{12}(\widehat{t}_{12})\right) + \left(\widehat{t}_{21} - c_O\right)\left(\Delta_{21}(\widehat{t}_{12}) + \widehat{q}_{12}(\widehat{t}_{12}) + K\right) - C_K \\
= \ & \widehat{t}_{12}\widehat{q}_{12}(\widehat{t}_{12}) + \widehat{t}_{21}\widehat{q}_{21}(\widehat{t}_{21}) - Kc_O - C_K + (\widehat{t}_{12} + c_O)\Delta_{12}(\widehat{t}_{12}) + (\widehat{t}_{21} - c_O)\Delta_{21}(\widehat{t}_{21}) \\
= \ & (\widehat{t}_{12} + c_O)\Delta_{12}(\widehat{t}_{12}) + (\widehat{t}_{21} - c_O)\Delta_{21}(\widehat{t}_{21}),
\end{aligned}$$

where we have used $BC_{CE}(\widehat{t}_{12}, \widehat{t}_{21}) = 0$, or

$$\widehat{t}_{12}\widehat{q}_{12}(\widehat{t}_{12}) + \widehat{t}_{21}\widehat{q}_{21}(\widehat{t}_{21}) - Kc_O - C_K = 0.$$

Now given $\widehat{t}_{12} > |\widehat{t}_{21}|$ and $\Delta_{12}(\widehat{t}_{12}) > \Delta_{21}(\widehat{t}_{21})$, we have $BC_{NCE}(\widehat{t}_{12}, \widehat{t}_{21}) > 0$. This completes the proof of Lemma 2.2. ■

Lemma 2.2 tells us that $\widehat{t}_{12}$ and $\widehat{t}_{21}$ are also in the choice set of the TSO if firms' bookings lead to the NCE. However, Proposition 2.2 tells us that the TSO prefers to choose the tariff combination (t^*_{12}, t^*_{21}) rather than implementing $(\widehat{t}_{12}, \widehat{t}_{21})$ if both pairs of tariffs are in its choice set. Therefore, we have

$$SW_{NCE}(t^*_{12}, t^*_{21}) > SW_{NCE}(\widehat{t}_{12}, \widehat{t}_{21}) > SW_{CE}(\widehat{t}_{12}, \widehat{t}_{21}),$$

which completes the proof of Lemma 2.1. ■

Chapter 3

Do firms sell forward for strategic reasons? A test based on the theory*

3.1 Introduction

As mentioned in Chapter 1, electricity and gas industries used to consist of vertically integrated monopolies, state-owned or not, operating under regulatory constraints. In each country or region there was a single monopolistic importer in place, which typically owned the transmission network and either sold directly to consumers or to downstream distribution monopolies. One-to-one negotiations was the standard of trade throughout the value chain and the different parties were typically subject to long-lasting contractual relationships.

Short- and long-run efficiency considerations have led energy policy makers worldwide to gradually restructure energy markets. A key feature has been the vertical separation of production and transportation activities. This separation has enabled the creation of spot commodity markets. The *Pool* in the UK, ISO in California, the real-time PJM market in Pennsylvania, New Jersey and Maryland, ERCOT in Texas, EPEXSPOT in Austria, France, Germany and Switzerland are examples in electricity; NBP in the UK, the Henry Hub in the US, the Zeebrugge Hub in Belgium and TTF in The Netherlands are examples in natural gas.

*This chapter is based on van Eijkel and Moraga-González (2010).

The 2000-2001 electricity crisis in California has revealed that the combined prevalence of price risks and market power in energy markets may have fatal consequences when risk-hedging mechanisms are absent (Bushnell, 2004). As a consequence, in nowadays restructuring, it is widely held that spot markets must necessarily be complemented with forward markets (Ausubel and Cramton, 2009). In an attempt to aid firms to contract forward, platforms have been created where property rights can more easily be transferred among the participants.[1] In addition, in some markets we have witnessed the creation of futures exchanges. Examples of markets for electricity futures are CALPX in California and EEX Power Derivatives in Austria, France, Germany and Switzerland; ENDEX runs a market for natural gas futures in The Netherlands, as well as markets for UK and Dutch electricity futures.

Facilitating forward transactions has the potential to deliver social benefits on two accounts. First, forward markets address the need of a firm *to hedge risks*. Forward contracts typically specify fixed delivery prices so risk-averse market participants can mitigate their exposure to price shocks in the spot market by acquiring a portfolio of futures. Central results in the literature relate to the decisions of a competitive risk-averse firm facing price uncertainty (see e.g Baron, 1970; Holthausen, 1979; and Sandmo, 1971). In the absence of a futures market, this type of firm turns out to restrict its output relative to what the firm would produce under certainty. The opening of a forward market restores the level of output that would prevail if uncertainty were removed.

Forward markets can deliver further social benefits in situations where firms wish to sell forward for *strategic* reasons. In their influential paper, Allaz and Vila (1993) show that forward contracts confer competitive advantages to Cournot firms so, even when there is no uncertainty at all about future market conditions, firms have incentives to engage in forward trading. By selling futures contracts at a pre-specified price, a firm ends up attaching a lower value to a high spot market price. As a result, a firm that sells forward is indirectly committing to an aggressive behavior in the spot market. This raises firm profitability, since competitors respond by adopting a compliant spot market strategy. Selling forward exhibits however the characteristics

[1] One development in natural gas has been the creation of virtual hubs, for example the NBP and TTF, as opposed to the more traditional physical hubs, like the Henry Hub and the Zeebrugge Hub. A physical hub is a location where several pipelines come together, so that total physical throughput is delivered at this point. By contrast, virtual hubs contain several entry and exit points that are interconnected, which implies that not all the gas traded has to flow through a single point in the pipeline system.

of a prisoner's dilemma. Because every seller has incentives to sell (part of) its output forward, the resulting equilibrium aggregate production is higher (and the price lower) than in the absence of a futures market.[2]

To the best of our knowledge, whether the forward market institution *by itself* is successful on these two fronts at a time is not well understood yet. One obvious reason for this lack of knowledge is that a great deal of the contracts we have observed in gas and electricity markets has not been dictated by market forces but imposed by the regulators in the form of gas release programs or vesting electricity contracts (Borenstein, 2002; Wolfram, 1999). A second reason is that disentangling the two rationales motivating firms to sell forward – strategic commitment and risk-hedging – from the field data is, at least, methodologically challenging; in addition, it requires a wealth of data on forward transactions. In the core of this chapter we propose an empirical strategy to separate the various incentives behind the contract cover of a firm. In the next chapter of this thesis we will apply this strategy to the Dutch natural gas market.

Our methodology to test whether firms use forward contracts for strategic reasons and/or for risk-hedging motives builds on the idea that commitment has value only if it is (imperfectly) observable (Allaz and Vila, 1993; Kao and Hughes, 1997). Inspired from this idea, we develop a model of the interaction of asymmetric risk-averse firms that compete in a forward market before they set quantities in a spot market. The key aspect of the modelling is that it introduces the extent to which forward positions are observable (or correctly inferred from the forward price) as a structural parameter that can be estimated provided there is variation in the number of participating firms.

In real-world energy markets, it is reasonable to assume that rivals' forward positions may be difficult to observe. First, where they exist, markets for natural gas and electricity futures are designed to be anonymous and this anonymity puts impediments for the forward *positions* of each individual rival firm to be observed with a reasonable precision. Second, even if in principle observation of the forward price may help firms to infer the rivals' aggregate forward position, the process of (forward) price discovery is far from simple. This is because some (or all) of the transactions in these markets are made over the counter (OTC) as organized exchanges are often bypassed by the traders or totally lacking.[3] OTC markets are

[2]The model of Allaz and Vila has been adapted to suit the particular organization of power markets in the UK by von der Fehr and Harbord (1992), Powell (1993), Newbery (1998) and Green (1999).

[3]Chapter 5 discusses in more detail the coexistence of OTC marketplaces and centralized ex-

relatively non-transparent and price indices for these markets, typically provided by broker associations of by specialized agencies, are based on a limited pool of recent transactions. By construction, price indices are complex statistics so it is unclear how much a participant in the market can learn about rivals' deviations from equilibrium play. Even if centralized futures markets are more transparent, seen that arbitrage opportunities across the exchanges and the OTC markets are not always fully exhausted, the existence of conflicting price signals (as the law of one price fails) further troubles the quality of the inferences market participants can make (see e.g. Anderson, Hu and Winchester, 2007; Bushnell, 2007).

Our model bridges between the extreme cases of full transparency (perfect observability of rivals' forward positions) and complete opacity of the forward market (no observability at all). By doing so, the model gains in flexibility to fit the data and helps us understand the extent to which the forward market provides the players with commitment possibilities.

We show how to estimate the model using data on total sales, forward sales, churn ratios and numbers of producers and wholesalers. Identification of the key parameter requires variation in the number of active wholesale firms. In the data set we use in the following chapter this variation comes from entry of new players in the market but in other studies the analyst could exploit variation in the number of producers and wholesalers across regional/separated markets. The empirical test exploits the effect that changes in the number of players has on the so-called *inverse hedge ratio* –defined as the total-to-forward-sales ratio.[4] Interestingly, for the linear model this ratio is independent of demand intercept and marginal cost so firms with similar aversion to risk hedge in the same way no matter their marginal costs of production and the state of the demand.

In a nutshell, the identification arguments are as follows. The incentives of a firm to trade forward are shaped by three forces. The first two, the risk-hedging effect and the strategic effect, are pro-contracts. The third is a *price* effect that arises because offering forward contracts lowers the spot price and, by arbitrage, the forward price too. This price effect actually puts a downward pressure on firm's (expected) profits and therefore makes forward contracting less attractive.

When the forward market is relatively opaque so that players have a difficult time to infer deviations from equilibrium play, the strategic effect is hardly present and the contract cover of a firm is the outcome of trading off the risk-hedging effect against the price effect. In that situation, as the number of competitors rises, the

changes in energy markets.

[4]To be precise, inverse hedge ratio = (spot sales + forward sales) / forward sales .

residual demand of an individual firm becomes less susceptible to demand shocks. Therefore, the incentive to hedge becomes weaker if more suppliers enter the market. The price effect, by contrast, stays constant if the number of suppliers in the market increases. As a result, by virtue of the first force, the inverse hedge ratio increases in the number of competitors.

By contrast, if the forward market is relatively transparent so that price and/or rival firms' forward positions are regularly and precisely observed, in addition to the risk-hedging and the price effects, the strategic effect plays a significant role. This strategic effect turns out to be stronger as more players are around. This is because the (marginal) gains from affecting the rivals' spot market strategy rise with the number of competitors. We show that the strategic effect may have a dominating influence in which case inverse hedge ratios turn out to be decreasing in the number of firms. This different impact of the number of firms on inverse hedge ratios in case forward positions can correctly be forecast by the market participants constitutes the source of identification of the strategic effect.

This chapter contributes to the literature that studies forward contracting of (essentially) non-storable goods.[5] Allaz (1992) and Allaz and Vila (1993) show that not only risk-hedging is important for firms to sell contracts in Cournot markets. Kao and Hughes (1997) discuss the role of the observability-of-forward-positions assumption. Mahenc and Salanié (2006) demonstrate that selling forward may have anticompetitive effects when firms compete in prices. Ferreira (2003) also encounters anticompetitive effects when firms are able to sell in a futures market at infinitely many moments prior to the opening of the spot market.[6] Our model extends previous work by examining an n-firm game with risk-averse players that are heterogeneous in their marginal costs of production and in their aversion to risk. We explore two variants of the model, one where firms observe demand shocks before the spot market opens, and one where the spot market remains uncertain. Although we cannot find closed-form solutions for the forward and spot sales of an individual firm, we derive its equilibrium (mean) inverse hedge ratio. These ratios turn out to have similar properties, the most important for our purposes that they fall in the number of players when the forward market is sufficiently transparent.

[5]Natural gas can be stored more easily than electricity but the costs of doing so are relatively high, so that for its most part production, delivery and consumption take place contemporaneously.

[6]See also Newbery (1998) and Green (1999), who study models where firms compete in the spot market using supply schedules. These papers show that, owing to the multiplicity of equilibria in supply functions, the optimal contract cover of a firm is intimately linked to the spot market equilibrium actually played.

There is also work that has focused more on forward and spot price differences in energy markets than on a firm's optimal contract cover. Longstaff and Wang (2004) document significant risk-premia in electricity forward prices. Bessembinder and Lemmon (2006) derive the equilibrium forward risk premium in a *competitive* model of the interaction of producers and retailers in the absence of speculators. Our work differs from these papers in that we consider market power on the supply side. This allows us to address the issue of whether firms sell futures contracts to hedge or to gain market power in the spot market.[7]

The rest of the chapter is organized as follows. The next section presents a two-period model of competition. In the first period, the forward market opens and firms sell futures contracts. In the second period, the spot market opens, firms sell quantities and delivery of all contracted and spot quantities takes places. This section also presents the main empirical prediction of our model. We exploit the equilibrium restrictions to develop an empirical strategy in Section 3.3. After having presented how to test for the existence of a strategic motive to contract forward, we study various extensions to our main framework. In Section 3.4, we generalize our model by allowing for nonlinear demand and general increasing and concave firm utility functions. Section 3.5 analyzes the magnitude of the error when applying the mean-variance approach to solve for firms' optimal inverse hedge ratio. In Section 3.6, we study a variation of the basic model by assuming that firms cannot condition their spot strategies on the demand realization. The chapter closes with a discussion of the main results and some concluding remarks. The proof for the main proposition of this chapter can be found in the Appendix.

3.2 A model of forward and spot contracting

Consider an oligopolistic market with n asymmetric risk-averse firms selling a homogeneous good. Firms are asymmetric on two accounts: they differ in their degree of

[7] An alternative, and complementary, approach to address this issue is to use controlled experiments. In a recent paper, Brandts, Pezanis-Christou and Schram (2008) set up laboratory experiments to study the efficiency effects brought about by the possibility of forward contracting. Working with deterministic demand and cost parameters, risk-hedging can be, if not fully eliminated, at least significantly reduced. Brandts *et al.* observe that significant price decreases and efficiency gains are obtained compared to the case in which only spot market trading is possible. Additional experimental evidence on the pro-competitive effects of futures contracts is provided by Coq and Orzen (2006). Ferreira, Kujal and Rassenti (2009) challenge this view and present experimental evidence to suggest that forward contracts make collusion more likely. Their results are in line with Liski and Montero (2006).

risk-aversion and have different marginal costs of production. Firms can sell output in the spot market; in addition, they can also sell (or buy) the good in a forward market.[8] Let s_i and x_i be, respectively, firm i's total spot and forward market sales; the total output firm i supplies on the market will be denoted $q_i(= s_i + x_i)$. The marginal cost of production of a firm i is denoted c_i.[9]

We assume that market demand is random and given by the linear-normal specification

$$p = a - bQ + \epsilon, \; \epsilon \sim N(0, \sigma^2), \tag{3.1}$$

where $Q = \sum_{i=1}^{n} q_i$ denotes the aggregate output delivered to consumers and ϵ is a zero-mean random shock normally distributed with standard deviation σ.[10] We assume that the realization of ϵ is observed when the spot market opens.[11] At that stage, a firm i chooses its spot sales s_i to maximize its spot market profits.[12]

At the forward market stage, by contrast, firms are uncertain about the price

[8]Forward contracts are contracts traded in the OTC market, while futures contracts change hands in centralized exchanges. Since both types of contracts serve the same objectives, we use them interchangeably throughout the chapter.

[9]In the natural gas industry, on the supply side of the market we typically encounter producers and wholesalers. The constant marginal cost assumption is probably a good approximation for the costs of extraction and shipping incurred by producers. European wholesalers typically import gas from producing countries such as Norway and Russia. Wholesalers have long-term take-or-pay contracts with foreign producers. Take-or-pay contracts stipulate that the buyer pays for a pre-specified minimum amount of gas, irrespective of whether the gas is actually taken (Masten and Crocker, 1985). Take-or-pay contracts also include a variety of (daily and yearly) flexibility clauses (Asche *et al.*, 2002; IEA, 2002). These clauses provide wholesalers with the necessary flexibility to adjust supply to demand shocks. Take-or-pay contracts are typically indexed to the oil price so the constant marginal cost assumption is also reasonable. Moreover, because wholesalers book import capacity assuming extreme weather conditions, transport capacity is typically not binding. Pipelines also allow for *line-pack*, that is, for the increase in the amount of gas the system can carry by temporarily raising its pressure.

[10]Even though producers and wholesalers may differ in that the latter face both price and cost risk, in what follows we will not make a distinction between their economic problems. Note also that in our linear model randomness of the demand is equivalent to randomness on the marginal cost.

[11]This assumption is not necessary. It reflects the idea that firms are typically well informed about the state of the demand when the spot market opens and use such a market to balance their portfolios. Later in Section 3.6 we develop the case in which at the spot market stage firms are still uncertain about the realization of ϵ. The main theoretical insights of the model generalize to such case (see Proposition 3.2).

[12]In our application, the demand side of the market is made of domestic retailers and exporting shippers. We do not model risk aversion on the demand side because retail prices in the Netherlands and the surrounding countries are non-regulated and a great deal of the retail contracts have variable prices (see e.g. von der Fehr and Hansen, 2010).

that will prevail in the market. As a result, at that stage, a firm views its monetary flow of profits as a random variable. We assume firms are risk averse and have constant absolute risk aversion (CARA) utility functions. Let π_i be the realized (forward and spot) monetary profits of a firm i. The utility function of a firm i is $u(\pi_i) = -e^{-\rho_i \pi_i}$, where $\rho_i > 0$ denotes firm i's degree of risk aversion.[13] Denote by $F(\pi_i)$ the distribution of the monetary profits π_i of a firm i. (Note that this distribution is endogenous and will be determined later.) Then a firm i will choose its forward sales x_i to maximize its expected utility:

$$E[u(\pi_i)] = \int -e^{-\rho_i \pi_i} dF(\pi_i). \tag{3.2}$$

For simplicity, future spot market profits are not discounted.[14]

Next, and central to our empirical strategy, we assume that whether firms observe each other's forward positions is uncertain. To model this idea, we introduce a Bernoulli random variable, denoted I, with parameter γ. If $I = 1$ forward positions become observable to the players and then we get the standard Allaz and Vila (1993) setting. By contrast, if $I = 0$ we obtain the case of unobservable forward trading, as discussed by Kao and Hughes (1997).[15] The parameter γ can then be interpreted as the degree of transparency of the forward market. As mentioned in the Introduction, another, and perhaps more compelling, interpretation of this parameter is that it reflects the ability of firms to infer deviations from the equilibrium path by looking at forward price changes.[16]

We further assume there is a fringe of outside speculators. These traders, which are assumed to be risk-neutral, do not have transmission capacity rights so they cannot physically deliver the commodity to the final customers. Speculators compete

[13]The case of risk-neutrality obtains when $\rho_i \to 0$ for all i.

[14]As it will become clear later, monetary profits are not normally distributed so maximizing (3.2) is not equivalent to maximizing the corresponding mean-variance specification. Section 3.5 analyzes the magnitude of the error when a firm's optimal contract cover is determined using the mean-variance approach.

[15]We model imperfect observability by assuming that firms either observe the (correct) forward price or they miss it altogether. An alternative way to model imperfect observability is by assuming that firms may observe forward prices that are wrong. In that case Bagwell (1995) shows that the value of commitment is fully destroyed; van Damme and Hurkens (1997) show that Bagwell's striking result relies on an unnecessary restriction to pure strategies.

[16]Forward markets are to some extent opaque. Many transactions occur over the counter and therefore are invisible to market participants. Forward price indices are published by brokers and specialized information agencies. Firms may be able to infer rivals' forward positions upon observation of those indices but the question is how well. We can think of γ as the fraction of times the firms are able to forecast how deviations from the equilibrium forward sales will affect the spot market price. In this sense, firms can be seen as been ignorant, or naive, $1-\gamma$ of the times.

à la Bertrand for the quantities offered in the forward market. We shall also assume that pure financial traders observe sellers' deviations from the equilibrium path. This assumption is based on the idea that speculators take positions that increase their exposure to risk in an attempt to (weakly) increase their wealth. As such, they have perhaps the strongest incentives to follow upon the forward market developments. For the model at hand, this assumption implies that a strong version of arbitrage (off and on the equilibrium path) between forward and spot markets holds.[17]

The timing of the game is as follows. In the first stage, firms put quantities in the forward market. Then the Bernoulli variable I is realized and forward positions become observable or not. Next, firms learn the demand shock ϵ. Finally, firms compete in quantities in the spot market and total sales are delivered. We now solve the game by backward induction.

3.2.1 Spot market stage

At the time the spot market opens, demand is certain and firm i chooses its spot sales s_i to maximize its spot market profits:

$$\pi_i^s = (p - c_i)s_i,$$

where p is the realized spot market price given in (3.1). For this, a firm i takes the spot market strategies and, when observed, the forward positions of the rival firms as given. In case of an opaque forward market, firm i makes a conjecture about the forward sales of its competitors. [18] The spot market equilibrium turns out to be in linear strategies. Putting the linearity of the strategies up front, we write the spot market strategy of a firm i as

$$s_i = A_i + B_i\epsilon, \ i = 1, ..., n. \tag{3.3}$$

When $I = 1$, which occurs with probability γ, firms observe each other forward positions. In that case, the realization of the spot market price can be written as follows:

$$p = a + (1 - b\sum_{j\neq i}^{n} B_j)\epsilon - bx_i - b\sum_{j\neq i}^{n} x_j - bs_i - b\sum_{j\neq i}^{n} A_j,$$

[17]Ferreira (2006) studies the role of the observability assumption at length. He argues that it is hard to reconcile the assumption that firms are not informed of the rivals' forward positions with the assumption that speculators observe deviations at the forward stage. As mentioned earlier, in the real-world forecasting quantities sold upon observing forward price indices is far from trivial, specially if firms are heterogeneous. Speculators are not gamblers but highly specialized investors whose profit critically depends on the quality of the forecasts they make.

[18]We require the conjectures to be correct in equilibrium.

where $\sum_{j\neq 1}^{n} x_j$ is the sum of the *actual* forward positions of firm i's competitors. Profit maximization at the spot market stage gives

$$s_i = \frac{1}{2b}(a + (1 - b\sum_{j\neq i}^{n} B_j)\epsilon - c_i - bx_i - b\sum_{j\neq i}^{n} x_j - b\sum_{j\neq i}^{n} A_j).$$

Using (3.3), we can solve for A_i and B_i:

$$A_i = \frac{a + \sum_{j\neq i}^{n} c_j - nc_i - bx_i - b\sum_{j\neq i}^{n} x_j}{b(n+1)},\ B_i = \frac{1}{b(n+1)}.$$

Therefore, conditional on the forward positions being observable, the equilibrium spot market output of firm i becomes

$$s_i^{I=1} = \frac{a + \epsilon + \sum_{j\neq i}^{n} c_j - nc_i - bx_i - b\sum_{j\neq i}^{n} x_j}{b(n+1)} \tag{3.4}$$

and the equilibrium spot market price equals

$$p^{I=1} = \frac{a + \epsilon + \sum_{i}^{n} c_i - bx_i - b\sum_{j\neq i}^{n} x_j}{n+1}.$$

The conditional reduced-form profits are then given by

$$\pi_i^{I=1} = b(s_i^{I=1})^2 + (f - c_i)x_i,$$

where f denotes the forward price.

When $I = 0$, which occurs with probability $1-\gamma$, firms do not observe each other's actions in the forward market. This implies that deviations of a firm i from the equilibrium path go undetected by the rival players. In that case, the price in the spot market is given by

$$p = a + (1 - b\sum_{j\neq i}^{n} B_j)\epsilon - bx_i - b\sum_{j\neq 1}^{n} \hat{x}_j - bs_i - b\sum_{j\neq i}^{n} A_j,$$

where $\sum_{j\neq i}^{n} \hat{x}_j$ is firm i's *conjecture* about the rivals' aggregate forward position. The first order condition (FOC) for the spot market stage yields

$$s_i = \frac{1}{2b}(a + (1 - b\sum_{j\neq i}^{n} B_j)\epsilon - c_i - bx_i - b\sum_{j\neq i}^{n} \hat{x}_j - b\sum_{j\neq i}^{n} A_j).$$

Because firm i does not observe deviations from the conjectured (equilibrium) forward sales of the rival firms, its spot market strategy is only affected by (a change in) its own forward position. We can solve for $\sum_{j\neq i}^{n} A_j$ and $\sum_{j\neq i}^{n} B_j$:

$$\sum_{j\neq i}^{n} A_j = \frac{(n-1)(a + c_i - b\hat{x}_i - b\sum_{j\neq i}^{n} \hat{x}_j) - 2\sum_{j\neq i}^{n} c_j}{b(n+1)},\ \sum_{j\neq i}^{n} B_j = \frac{n-1}{b(n+1)}. \tag{3.5}$$

As a result, conditional on the forward positions not being observed, the spot market sales of firm i are

$$s_i^{I=0} = \frac{a + \epsilon + \sum_{j\neq i}^{n} c_j + b(n-1)\hat{x}_i/2 - nc_i - b(n+1)x_i/2 - b\sum_{j\neq i}^{n}\hat{x}_j}{b(n+1)} \tag{3.6}$$

and the realized market price becomes

$$p^{I=0} = \frac{a + \epsilon + c_i + \sum_{j\neq i}^{n} c_j + b(n-1)/2\hat{x}_i - b(n+1)x_i/2 - b\sum_{j\neq i}^{n}\hat{x}_j}{n+1}.$$

The conditional profit of firm i's equals

$$\pi_i^{I=0} = b(s_i^{I=0})^2 + (f - c_i)x_i.$$

3.2.2 Forward market stage

At the forward market stage, firms sell (or buy) part of their total output in the futures market to maximize their expected utility.[19] Note that $u(\pi_i) = Iu(\pi_i^{I=1}) + (1-I)u(\pi_i^{I=0})$. Using the expressions for the conditional profits derived above, the expected utility of firm i is thus given by

$$E[u(\pi_i)] = -\gamma \int e^{-\rho_i \pi_i^{I=1}} f(\epsilon)d\epsilon - (1-\gamma)\int e^{-\rho_i \pi_i^{I=0}} f(\epsilon)d\epsilon,$$

where $f(\epsilon)$ is the density function of the normal distribution with zero mean and variance given by σ^2.

A firm i picks its amount of forward sales x_i to maximize its expected utility. It is instructive to write the FOC as follows:

$$\gamma \int \rho_i e^{-\rho_i \pi_i^{I=1}} \left(\frac{\partial \pi_i^{I=1}}{\partial x_i} + \sum_{j=1}^{n} \frac{\partial \pi_i^{I=1}}{\partial s_j}\frac{\partial s_j^{I=1}}{\partial x_i} \right) f(\epsilon)d\epsilon +$$
$$(1-\gamma)\int \rho_i e^{-\rho_i \pi_i^{I=0}} \left(\frac{\partial \pi_i^{I=0}}{\partial x_i} + \frac{\partial \pi_i^{I=0}}{\partial s_i}\frac{\partial s_i^{I=0}}{\partial x_i} \right) f(\epsilon)d\epsilon = 0.$$

In equilibrium $\hat{x}_i = x_i$ for all i and so is $\pi_i^{I=1} = \pi_i^{I=0} = \pi_i$ and $\partial\pi_i^{I=1}/\partial x_i = \partial\pi_i^{I=0}/\partial x_i = \partial\pi_i/\partial x_i$; therefore, this FOC can more compactly be written as follows:

$$\int \rho_i e^{-\rho_i \pi_i} \left(\frac{\partial \pi_i}{\partial x_i} + (1-\gamma)\frac{\partial \pi_i^{I=0}}{\partial s_i}\frac{\partial s_i^{I=0}}{\partial x_i} + \gamma \sum_{j=1}^{n} \frac{\partial \pi_i^{I=1}}{\partial s_j}\frac{\partial s_j^{I=1}}{\partial x_i} \right) f(\epsilon)d\epsilon =$$

$$\int \rho_i e^{-\rho_i \pi_i} \left(-bx_i + (1-\gamma)\frac{bx_i}{2} + \gamma\frac{bx_i + (n-1)\,b(s_0 + x_i)}{n+1} - \frac{\epsilon}{n+1} + \gamma\frac{(n-1)\epsilon}{(n+1)^2} \right) f(\epsilon)d\epsilon =$$

[19]We do not a priori restrict firms' level of forward trading to be positive. However, in equilibrium each firm will sell a non-negative amount in the forward market.

$$\int \rho_i e^{-\rho_i \pi_i} \left(-\frac{bx_i}{2} - \frac{\epsilon}{n+1} + \gamma \frac{b(n-1)(x_i/2 + s_0)}{(n+1)} + \gamma \frac{(n-1)\epsilon}{(n+1)^2} \right) f(\epsilon) d\epsilon = 0, \tag{3.7}$$

where

$$s_0 = \frac{a + \sum_{j \neq i} c_j - nc_i - bx_i + b \sum_{j \neq i} x_j}{b(n+1)}.$$

The first term of this equation (after the integral sign) represents marginal utility from (monetary) profit, while the term between parentheses is the marginal monetary profit from selling futures contracts. A firm i chooses its amount of futures x_i to make the expected value of the product of marginal utility and marginal monetary profit equal to zero.

The incentives of a firm i to sell forward are shaped by three forces. There is a risk-hedging effect, a strategic effect and a price effect. The first two forces are pro-contracts; the third one dampens the incentives to sell futures. These three forces can actually be seen after taking a closer look at Equation (3.7). To see them more clearly, it is useful to consider the two extreme cases of complete opacity ($\gamma = 0$) and complete transparency ($\gamma = 1$) of the forward market.

When forward positions cannot be observed by the rivals the strategic effect is absent and Equation (3.7) simplifies to

$$\begin{aligned} &\int \rho_i e^{-\rho_i \pi_i} \left(\frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i^{I=0}}{\partial s_i} \frac{\partial s_i^{I=0}}{\partial x_i} \right) f(\epsilon) d\epsilon = \\ &\int \rho_i e^{-\rho_i \pi_i} \left(-\frac{bx_i}{2} - \frac{\epsilon}{n+1} \right) f(\epsilon) d\epsilon = 0. \end{aligned} \tag{3.8}$$

In parenthesis we see the direct effect of selling forward on a firm's monetary profits, along with a second effect that goes via its own spot market strategy, s_i. This joint effect is clearly negative and has a deterministic component and a random component. The deterministic component, $-bx_i/2$, constitutes a negative *price effect* that is independent of the number of firms. A firm that puts one unit more in the forward market cuts its spot sales by half a unit (see Equation (3.6)), so its total sales increase. This results in a fall in the spot market price, which is anticipated by the speculators and therefore the forward price falls too.[20] This own price effect dampens the incentives to put futures in the market, which explains why a risk-neutral monopolist would choose not to engage in forward contracting at all (see

[20] The fall in the forward price originates from the assumption that speculators observe the forward quantities (Ferreira, 2006). Since they anticipate a higher total quantity to be delivered when the spot market closes, they correspondingly lower the prices they bid for the quantities on sale in the futures market.

Tirole, 2006, p. 216-17). Since this effect is always negative no matter the number of firms, it is also true that a risk-neutral oligopolist would opt out of the contract market (Hughes and Kao, 1997).

The random component explains the *risk-hedging* motive. Note that a firm that increases its contract cover away from zero lowers its exposure to demand shocks by $\epsilon/(n+1)$ (see Equation (3.8)). This random component is negatively correlated with ϵ and so is the marginal utility from monetary profit (since profit increases in ϵ and the utility function is concave). As a result, the covariance between marginal utility and marginal profit is positive, giving rise to the risk-hedging incentive of selling forward contracts. When contracts cannot be observed by the market participants, the optimal contract cover of a firm i is the outcome of trading off the (positive) risk-hedging motive against the (negative) price effect.

When forward positions are easily observable by the firms, or can easily be inferred from the forward price, $\gamma = 1$ and (3.7) simplifies to

$$\int \rho_i e^{-\rho_i \pi_i} \left(-\frac{bx_i}{2} - \frac{\epsilon}{(n+1)} + \frac{b(n-1)}{(n+1)}(x_i/2 + s_0) + \frac{(n-1)\epsilon}{(n+1)^2} \right) f(\epsilon) d\epsilon = 0. \qquad (3.9)$$

In this case there is a third, *strategic*, effect of selling futures. This effect also has a deterministic component and a random component. Suppose the firms are risk-neutral. By the strategic effect, a firm that puts units in the forward market positively affects its profit via the spot market strategies of the rival firms. This gives firm i an incentive to sell forward, since by doing so it benefits from rival firms' cuts in their spot sales (Allaz and Vila, 1993). The additional random term has a positive sign and this implies that it works counter to the risk-hedging effect discussed above. This is because, since the rival firms cut their spot sales, the effect of putting one unit forward is less effective at lowering exposure to price shocks. However, the aggregate random component in Equation (3.9) is still negative and decreasing in n. This tells us that firms have an incentive to hedge against risk also in a transparent forward market, but that the marginal gains from doing it become smaller the more firms are around.

Obviously, the importance of the strategic motive depends on the likelihood forward positions are learnt by the players. Moreover, because the risk-hedging and the strategic effects of selling forward on a firm's expected utility are intertwined, it is now clear why it is difficult to disentangle them using data from the field. In the remainder of this chapter, our main focus will be on the equilibrium inverse hedge ratio of an individual firm i, defined as total-to-forward-sales (or q_i/x_i) ratio. Though the forward and the spot sales of an individual firm cannot be computed explicitly, we now show how one can easily derive the stochastic process of a firms's inverse hedge ratio. This ratio has useful properties that we will exploit in the empirical application.

After some algebra, the FOC given by (3.7) simplifies to

$$\left(a+\sum_{j\neq i} c_j - nc_i - bx_i - b\sum_{j\neq i} x_j\right)\left(\frac{1}{n+1}-\frac{2b\gamma+b(n+1)(1-\gamma)}{2\rho_i\sigma^2+b(n+1)^2}\right)-$$
$$x_i\frac{2b\gamma+b(n+1)(1-\gamma)}{2(n+1)}=0.$$

Solving for x_i gives

$$x_i=\frac{2(b(n^2-1)\gamma+2\rho_i\sigma^2)(a+\sum_{j\neq i}c_j-nc_i-b\sum_{j\neq i}x_j)}{b(b(n+1)^3-b(n-1)^2(n+1)\gamma+2(3+\gamma+n(1-\gamma))\rho_i\sigma^2)}.$$

Using equation (3.4), we can write firm i's total output $q_i = s_i + x_i$ as

$$q_i=\frac{n}{n+1}x_i+\frac{a+\sum_{j\neq i}c_j-nc_i-b\sum_{j\neq i}x_j}{b(n+1)}+\frac{\epsilon}{b(n+1)}.$$

It will prove convenient to measure the relationship between forward and spot sales by the inverse hedge ratio:

$$\frac{q_i}{x_i}=\frac{b(n+1)^2(n+1+(n-1)\gamma)+2(3+\gamma+(3-\gamma)n)\rho_i\sigma^2}{2(n+1)(b(n^2-1)\gamma+2\rho_i\sigma^2)}+\frac{1}{b(n+1)x_i}\epsilon. \quad (3.10)$$

As can been seen from Equation (3.10), the inverse hedge ratio is normally distributed. The following proposition discusses some more properties of the equilibrium inverse hedge ratio.

Proposition 3.1 *In equilibrium, the mean of the inverse hedge ratio of a firm i, defined as total-to-forward-sales ratio, is given by*

$$\Gamma_i \equiv \frac{(n+1)^2(n+1+\gamma(n-1))+2(3(n+1)-\gamma(n-1))\frac{\rho_i\sigma^2}{b}}{2(n+1)(\gamma(n^2-1)+2\frac{\rho_i\sigma^2}{b})}. \quad (3.11)$$

This mean of the inverse hedge ratio, Γ_i, satisfies the following properties:
(i) It is independent of the demand intercept parameter a and of the firm marginal cost c_i, but increases in the demand slope parameter b.
(ii) It decreases as the risk-aversion parameter of the firm ρ_i goes up, or as demand volatility σ^2 increases.
(iii) It decreases as the probability that forward positions are observed γ increases
(iv) There exists a critical parameter $\tilde{\gamma}(n)$ such that: For all $\gamma \leq (\geq)\tilde{\gamma}(n)$, Γ_i increases (decreases) in the number of firms n.

Moreover, if firms are symmetric ($c_i = c, \rho_i = \rho$ for all i), the variance of the inverse hedge ratio of the firms decreases in a, ρ and σ^2, and increases in c, b and in γ.

The proof is in the Appendix.

The main properties of the inverse hedge ratio as stated in Proposition 3.1 need some further explanation. First, the inverse hedge ratio does not depend on the demand parameter a and the cost parameter c_i. This means that firms with similar risk aversion hedge in the same way on average, no matter how much they differ in their marginal cost of production. In addition, it is interesting to see that inverse hedge ratios in periods of demand expansion are similar to those in periods of demand contraction. This result, of course, rests on the linearity assumptions of the demand and cost functions. However, it should be seen as a reasonable approximation that is useful because it allows us to estimate the model without cost and demand data.

Inverse hedge ratios go down when firms becomes more risk averse, when demand uncertainty increases, or when the transparency of the forward market goes up. The former two results are driven by the risk-hedging rationale: the higher the degree of risk aversion (or the greater the uncertainty), the more a firm wants to hedge in the forward market instead of selling spot. The latter is explained by the strategic motive, since a high level of contract cover is worth more to a firm the more convincing the commitment is.

The most interesting feature of the inverse hedge ratio, at least for our purposes, is that whether firm entry/exit has an upward or downward effect on this ratio depends on the extent to which the forward market is transparent. If the futures market is relatively opaque and rivals' futures contracts go often unobserved, the strategic effect is hardly present and the contract cover of a firm trades off the the risk-hedging effect against the price effect. In that situation the incentive to hedge against demand shocks becomes weaker (see Equation (3.8)) if more suppliers enter the market, which pushes up the inverse hedge ratio of an individual firm. This is because demand uncertainty is revealed before the spot market opens and therefore the demand shock is partly absorbed by the rivals' spot strategies. As a result, the residual demand of a particular firm at the spot stage is less susceptible to demand shocks the higher the number of competitors. By contrast, the price effect appears not to depend on the number of competitors (see Equation (3.8)). Therefore, it is clear that when the forward market is relatively obscure, inverse hedge ratios increase in the number of suppliers. For the extreme case of $\gamma = 0$ we in fact get

$$\Gamma_i(\gamma = 0) = \frac{6\rho_i\sigma^2 + b(n+1)^2}{4\rho_i\sigma^2},$$

which goes up in n.

If the futures market is more transparent and the contract positions of the rivals are regularly observed, in addition to the risk-hedging effect and the price effect, the strategic effect plays a significant role. Note from (3.9) that the strategic effect becomes more prominent as more players are active in the market. This is because for a firm the marginal gains from affecting its rivals' spot market strategies are higher the more competitors it faces. While the risk-hedging and the price effect (weakly) decrease as the number of competitors increases, we show that the strategic effect may have a dominating influence. For the extreme situation $\gamma = 1$, we obtain

$$\Gamma_i(\gamma = 1) = 1 + \frac{1}{n+1} + \frac{2b}{b(n^2-1) + 2\rho_i \sigma^2},$$

which clearly decreases in n.

As shown in Proposition 3.1, for intermediate cases, the relationship between the number of firms and the inverse hedge ratio depends on how likely it is that forward positions will be observed. This is illustrated in Figure 3.1.

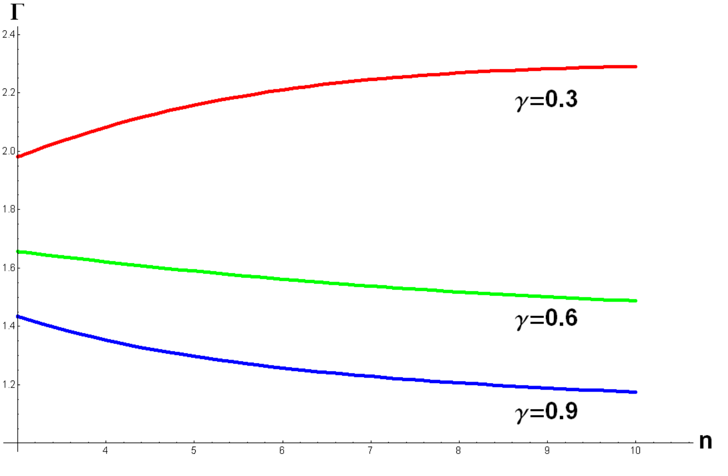


Figure 3.1: The inverse hedge ratio and the number of firms ($\rho_i = 4$, $\sigma^2 = 1$, $b = 1$)

3.3 Empirical strategy

We seek to answer the question whether firms sell futures for strategic reasons, for risk-hedging considerations, or for both. If firms' forward positions were totally opaque to the agents in the market, strategic reasons would not play any role and therefore the observed inverse hedge ratios in the data would only be explained by risk-hedging considerations. Answering this inquiry thus amounts to finding out the extent to which firms can observe each other's forward sales. Or, in different words, figuring out the ability of the players to forecast correctly the aggregate position of the rivals' upon observing the forward price/index.

If one were provided with firms' forward and spot sales data corresponding to various levels of observability and risk, one could estimate the effects of these two factors on the hedge ratio. The problem with this approach is that these variables are hard to measure. One could for example gather data from different regional markets. Within-market price dispersion could be used as a measure of price risk. However, it is not clear how to measure the extent to which firms are capable of deducing deviations from changes in the forward price. The analyst would have to make a priori assumptions about the observability parameter γ. Instead, we propose to estimate the model in Section 3.2 structurally. In the next chapter, we do this for the Dutch wholesale market for natural gas. For this market, we have obtained the minimal set of data: forward and spot sales, churn ratios and number of producers and wholesalers. We will now discuss the empirical approach that can be applied when one collects a data set similar to the one we have for the Dutch gas market.

The variable of interest is the inverse hedge ratio of an individual firm i. As shown above, the inverse hedge ratio of an individual firm i has a random generating process given by

$$\frac{q_i^*}{x_i^*} = \frac{b(n+1)^2(1+n+(n-1)\gamma) + 2(3+\gamma+(3-\gamma)n)\rho_i\sigma^2}{2(n+1)(b(n^2-1)\gamma + 2\rho_i\sigma^2)} + \frac{1}{b(n+1)x_i^*}\epsilon. \quad (3.12)$$

We can rewrite equation (3.12) as

$$(n+1)q_i^* = \frac{(n+1)^2(1+n+(n-1)\gamma) + 2(3+\gamma+(3-\gamma)n)\frac{\rho_i\sigma^2}{b}}{2((n^2-1)\gamma + 2\frac{\rho_i\sigma^2}{b})}x_i^* + \frac{1}{b}\epsilon. \quad (3.13)$$

Using individual firm level data on total quantities brought to the market, forward sales and number of wholesalers, the system of equations in (3.13) can be fitted to the data. Identifying assumptions are that the slope of the demand function b and the demand volatility parameter σ are constant over the sample period; moreover, we assume that variation in the number of players n is exogenous.[21] Since these equations are non-linear in the parameters of interest, one has to apply non-linear least squares (NLS). Notice that the parameters ρ_i, σ and b cannot be separately identified. However, with the appropriate (firm-level) data, one could estimate relative risk-aversion parameters across firms, i.e. ρ_i/ρ_j. The identification of these

[21] It may be argued that the number of players is determined jointly with the hedge ratios. Economic theory suggest the demand and cost parameters as clear determinants of n. If this dependence is not clearly controlled for by the variation in the forward sales of a firm x_i, which clearly depend on a and c_i, then an endogeneity problem would arise. In the following chapter, where we apply the empirical strategy to the Dutch gas market, we deal with this issue.

parameters would stem from variation in the hedge ratios of the different firms. If some firms were systematically seen to hedge more than others, this would provide information on the extent to which the former firms have greater risk-aversion than the latter.

The identification of the observability parameter γ stems from variation in the number of wholesalers n. As shown above, when forward positions are relatively transparent to the firms, the model predicts that an individual firm responds to entry by *decreasing* its inverse hedge ratio. By contrast, if firms' forward sales are relatively opaque and rivals' rarely observe them, then an individual firm *increases* its inverse hedge ratio as a response to entry. It is precisely this differential effect of entry that enables the identification of the observability parameter γ using data containing variation in the number of players.

Unfortunately, due to confidentiality reasons, individual firm level data are often not publicly available so one has to rely on aggregate forward and spot sales. To work with this type of data, we proceed by aggregating at the market level. For this we need to assume that all firms have similar risk aversion parameters, i.e., $\rho_i = \rho$ for all $i = 1, 2, ..., n$. Summing up for all firms in (3.13), we get

$$\frac{n+1}{n}\sum_{i=1}^{n} q_i = \frac{b(n+1)^2(1+n+(n-1)\gamma) + 2(3+\gamma+(3-\gamma)n)\frac{\rho\sigma^2}{b}}{2n((n^2-1)\gamma + 2\frac{\rho\sigma^2}{b})}\sum_{i=1}^{n} x_i + \frac{1}{b}\epsilon. \quad (3.14)$$

Note that $\sum_{i=1}^{n} q_i = \sum_{i=1}^{n} s_i + \sum_{i=1}^{n} x_i$, so that equation (3.14) can be rewritten as

$$\frac{n+1}{n}\sum_{i=1}^{n} s_i = \frac{n+1}{n}(\Gamma(\cdot) - 1)\sum_{i=1}^{n} x_i + \frac{\epsilon}{b}, \quad (3.15)$$

where $\Gamma(\cdot)$ is the hedge ratio as defined in Proposition 3.1 for symmetric firms. This equation can be fit to the data by applying NLS. In Chapter 4, we apply the empirical strategy described above to the Dutch wholesale market for natural gas.

3.4 A general model of forward contracting

In this section, we show that the effects of forward contracting discussed in the previous section carry over to a more general version of our basic framework. We continue to have n firms producing a homogeneous good at constant (firm-specific) marginal cost c_i. Sellers now face the following general inverse demand function:

$$p = P(Q) + \epsilon, \ \epsilon \sim (0, \sigma^2),$$

where $Q = \sum_{i=1}^{n} q_i$ and ϵ is a, not necessarily normally distributed, additive random shock with zero mean and variance σ^2. It is assumed that the deterministic part of the inverse demand function, $P(Q)$, is twice differentiable, monotonically decreasing in Q and (weakly) concave. Further, we maintain the assumption that firms get to know the realization of the demand shock before the spot market opens.

Firm i chooses its forward position and spot sales so as to maximize its expected utility, where utility is now represented by the function $u_i = U_i(\pi_i)$, with $U' > 0$ and $U'' < 0$. This function captures a wide range of risk preferences, including constant absolute risk aversion (CARA) and constant relative risk aversion (CRRA). Again, forward positions are observed only with probability γ.

3.4.1 The spot market stage

At the time the spot market opens, demand uncertainty is resolved and firm i chooses its spot sales s_i to maximize its profits, given its own forward position and, if observed, the forward strategies of its rivals. In case of observability, the system of n spot market FOCs is given by

$$P\left(s_i + x_i + \sum_{j\neq i}^{n}(s_j + x_j)\right) + \epsilon - c_i + P's_i = 0, \quad i = 1, 2, ..., n. \tag{3.16}$$

Let $\{s_i^{I=1}\}_{i=1}^n$ denote the firms' spot sales that solve this system of FOCs. When the forward market institution is not transparent, the optimal spot outputs are given by $\{s_i^{I=0}\}_{i=1}^n$ and solve the following system of FOCs:

$$P\left(s_i + x_i + \sum_{j\neq i}^{n}(s_j + \hat{x}_j)\right) + \epsilon - c_i + P's_i = 0, \quad i = 1, 2, ..., n, \tag{3.17}$$

where $\hat{x}_j$ denotes firms' conjectures about the forward position of producer j.

To see how firm i affects its own spot output and the spot strategies of rival firms by selling in a transparent forward market, we first differentiate the system of FOCs, given by (3.16), to get

$$\mathbf{Mx} = -\mathbf{b},$$

where

$$\mathbf{M} = \begin{pmatrix} 2P' + P''s_1 & P' + P''s_1 & \cdots & P' + P''s_1 \\ P' + P''s_2 & 2P' + P''s_2 & \cdots & P' + P''s_2 \\ \vdots & & \ddots & \vdots \\ P' + P''s_n & P' + P''s_n & \cdots & 2P' + P''s_n \end{pmatrix},$$

$$\mathbf{x} = \left[\frac{\partial s_1}{\partial x_i}\ \frac{\partial s_2}{\partial x_i}\ \cdots\ \frac{\partial s_n}{\partial x_i}\right]'$$

and

$$\mathbf{b} = [P' + P''s_1 \quad P' + P''s_2 \quad \cdots \quad P' + P''s_n]'.$$

Note that $\mathbf{M}$ can be written as $\mathbf{M} = \mathbf{G} + \mathbf{H}$, where $\mathbf{G} = P'\mathbf{I}$ ($\mathbf{I}$ being the identity matrix) and $\mathbf{H}$ is a matrix of rank one with columns $[P' + P''s_1 \quad P' + P''s_2 \quad \cdots \quad P' + P''s_n]'$. Then from Miller (1981) we know that the inverse of $\mathbf{M}$ can be written as

$$\mathbf{M}^{-1} = (\mathbf{G} + \mathbf{H})^{-1} = \mathbf{G}^{-1} - \frac{1}{1+g}\mathbf{G}^{-1}\mathbf{H}\mathbf{G}^{-1}, \tag{3.18}$$

where $g = tr\mathbf{H}\mathbf{G}^{-1}$. Substituting $\mathbf{G}^{-1}$ and $\mathbf{H}$ into (3.18) then yields

$$\mathbf{M}^{-1} = \frac{1}{P'}\begin{pmatrix} 1-\alpha_1 & -\alpha_1 & \cdots & -\alpha_1 \\ -\alpha_2 & 1-\alpha_2 & \cdots & -\alpha_2 \\ \vdots & & \ddots & \vdots \\ -\alpha_n & -\alpha_n & \cdots & 1-\alpha_n \end{pmatrix},$$

where

$$\alpha_j \equiv \frac{P' + P''s_j}{(n+1)P' + P''\sum_{i=1}^n s_i}, \quad j = 1, 2, ..., n.$$

It thus follows that

$$\frac{\partial s_j^{I=1}}{\partial x_i} = -\frac{P' + P''s_j}{(n+1)P' + P''\sum_{i=1}^n s_i} < 0, \quad j = 1, 2, ..., n, \tag{3.19}$$

which tells us that firm i's forward position has a negative effect on both firm i's own spot sales and the spot output of its competitors.

When the hedging decisions remain hidden, firm i's forward output has no influence on the rivals' spot strategies. To see how firm i adjusts its spot supply due to a change in its own forward position, we differentiate (3.17) with respect to x_i to obtain

$$\frac{\partial s_i^{I=0}}{\partial x_i} = -\frac{P' + P''s_i}{2P' + P''s_i} < 0. \tag{3.20}$$

3.4.2 The forward market stage

Moving one stage back, firm i chooses the amount of contracts to maximize its expected utility:

$$\max_{x_i} E\left[U\left(\gamma\pi_i^{I=1} + (1-\gamma)\pi_i^{I=0}\right)\right],$$

where

$$\pi_i^{I=1} = \left(P\left(s_i^{I=1}(x_i) + \sum_{j\neq i}^n s_j^{I=1}(x_i) + x_i + \sum_{j\neq i}^n \hat{x}_j\right) + \epsilon - c_i\right)s_i^{I=1} + (f - c_i)x_i$$

and

$$\pi_i^{I=0} = \left(P\left(s_i^{I=0}(x_i) + \sum_{j\neq i}^{n} s_j^{I=0}(\hat{x}_i) + x_i + \sum_{j\neq i}^{n} \hat{x}_j \right) + \epsilon - c_i \right) s_i^{I=0} + (f - c_i)x_i$$

are the full profit expressions at the forward stage. We retain the assumption that the forward market is efficient, so $f = E(p) = P\left(\sum_{i=1}^{n} Es_i + \sum_{i=1}^{n} x_i\right)$. The optimal level of forward contracting solves

$$E\left[U'(\cdot)\Upsilon(\cdot)\right] = 0,$$

where

$$\Upsilon(\cdot) \equiv \gamma\left(\frac{\partial \pi_i^{I=1}}{\partial x_i} + \frac{\partial \pi_i^{I=1}}{\partial s_i}\frac{\partial s_i^{I=1}}{\partial x_i} + \sum_{j\neq 1}^{n} \frac{\partial \pi_i^{I=1}}{\partial s_j}\frac{\partial s_j^{I=1}}{\partial x_i}\right) + (1-\gamma)\left(\frac{\partial \pi_i^{I=0}}{\partial x_i} + \frac{\partial \pi_i^{I=0}}{\partial s_i}\frac{\partial s_i^{I=0}}{\partial x_i}\right).$$

Applying the equilibrium property $\hat{x}_i = x_i$ and $s_i^{I=1} = s_i^{I=0} = s_i$ for all i yields $\pi_i^{I=1} = \pi_i^{I=0} = \pi_i$ and $\partial \pi_i^{I=1}/\partial x_i = \partial \pi_i^{I=0}/\partial x_i = \partial \pi_i/\partial x_i$; therefore, the FOC simplifies to

$$E\left[U'\left(\frac{\partial \pi_i}{\partial x_i} + \gamma\left(\frac{\partial \pi_i^{I=1}}{\partial s_i}\frac{\partial s_i^{I=1}}{\partial x_i} + \sum_{j\neq i}^{n} \frac{\partial \pi_i^{I=1}}{\partial s_j}\frac{\partial s_j^{I=1}}{\partial x_i}\right) + (1-\gamma)\frac{\partial \pi_i^{I=0}}{\partial s_i}\frac{\partial s_i^{I=0}}{\partial x_i}\right)\right] = 0.$$

Suppose that the strategic effect is not present, so $\gamma = 0$. Then, firm i trades forward contracts up to the point where

$$Cov\left(U', \left(\frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i^{I=0}}{\partial s_i}\frac{\partial s_i^{I=0}}{\partial x_i}\right)\right) + E(U')E\left(\frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i^{I=0}}{\partial s_i}\frac{\partial s_i^{I=0}}{\partial x_i}\right) = 0. \quad (3.21)$$

Notice that

$$\begin{aligned}&\frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i^{I=0}}{\partial s_i}\frac{\partial s_i^{I=0}}{\partial x_i} = \\ &P's_i + f - c_i + \frac{\partial f}{\partial x_i}x_i + (p - c_i + P's_i)\frac{\partial s_i^{I=0}}{\partial x_i} + \frac{\partial f}{\partial Es_i^{I=0}}E\frac{\partial s_i^{I=0}}{\partial x_i}x_i, \end{aligned} \quad (3.22)$$

where the last term yields the effect of forward sales on the forward price via the change in speculators' expectation of the spot output. Using the FOC at the spot stage and taking into account that $\partial f/\partial Es_i^{I=0} = \partial f/\partial x$, (3.22) simplifies to

$$\frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i^{I=0}}{\partial s_i}\frac{\partial s_i^{I=0}}{\partial x_i} = f + \frac{\partial f}{\partial x_i}\left(1 + E\frac{\partial s_i^{I=0}}{\partial x_i}\right)x_i - p.$$

Equation (3.21) can then be rewritten as follows:

$$Cov(U', -p) + E(U')\frac{\partial f}{\partial x_i}\left(1 + E\frac{\partial s_i^{I=0}}{\partial x_i}\right)x_i = 0. \quad (3.23)$$

It is easy to see that the covariance term in equation (3.23), which represents the risk-hedging effect, is strictly positive. First note that $\frac{\partial U'}{\partial \epsilon} = U'' \frac{\partial \pi_i}{\partial \epsilon}$. Since by assumption $U'' < 0$ and

$$\frac{\partial \pi_i}{\partial \epsilon} = \frac{\partial p}{\partial \epsilon} s_i + (p - c_i) \frac{\partial s_i}{\partial \epsilon} > 0, \tag{3.24}$$

we get $\frac{\partial U'}{\partial \epsilon} < 0$.[22] Now, provided that the spot price increases in the demand shock (see Footnote 22), one obtains that $Cov(U', -p)$ is positive.

Next, the second term of equation (3.23) represents the price effect. To find the sign of this term, first notice that from equation (3.20) we get

$$\frac{\partial s_i^{I=0}}{\partial x_i} = -\frac{P' + P'' s_i(\epsilon)}{2P' + P'' s_i(\epsilon)} > -1 \quad \forall s_i \geq 0.$$

This also implies that

$$E \frac{\partial s_i^{I=0}}{\partial x_i} = -\int \frac{P' + P'' s_i}{2P' + P'' s_i} f(\epsilon) d\epsilon > -\int f(\epsilon) d\epsilon = -1.$$

Now, given that an increase in the forward obligations pushes down the forward price, so $\partial f / \partial x_i < 0$, the second term of Equation (3.23) becomes negative. This shows the utility-reducing price effect of selling forward. Concluding, in case of an opaque forward market firms sell forward only for risk-hedging reasons, though this incentive is weakened by the negative price effect.

In case the strategic effect is present, we have $\gamma = 1$ and firm i then chooses the level of forward sales that solves

$$E \left[U'(\cdot) \left(\frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i^{I=1}}{\partial s_i^{I=1}} \frac{\partial s_i^{I=1}}{\partial x_i} + \sum_{j \neq i}^{n} \frac{\partial \pi_i^{I=1}}{\partial s_j^{I=1}} \frac{\partial s_j^{I=1}}{\partial x_i} \right) \right] = 0. \tag{3.25}$$

Taking into account the FOC at the spot stage, equation (3.19) and $\partial f / \partial E s_i^{I=0} = \partial f / \partial x$, we get

$$\frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i^{I=1}}{\partial s_i^{I=1}} \frac{\partial s_i^{I=1}}{\partial x_i} = f + \frac{\partial f}{\partial x_i} \left(1 + E \frac{\partial s_i^{I=1}}{\partial x_i} \right) x_i - p.$$

[22] To find the effect of the demand shock on the spot output, it is easily obtained that $\frac{\partial s_i}{\partial \epsilon} = \mathbf{M}_i^{-1} \iota = -\frac{1}{P'} \frac{P' + \left(\sum_{j \neq i}^{n} s_j - (n-1) s_i \right) P''}{(n+1) P' + P'' \sum_{i=1}^{n} s_i}$, where $\mathbf{M}_i^{-1}$ is the ith row of the matrix in (3.18) and ι is the unit vector (of size n). Thus, the demand shock has a positive impact on firm i's spot sales as long as firms are relatively symmetric or demand is not too concave. Next, we obtain $\frac{\partial p}{\partial \epsilon} = 1 + \sum_{i=1}^{n} P' \frac{\partial s_i}{\partial \epsilon} = \frac{P' + P'' \sum_{i=1}^{n} s_i}{(n+1) P' + P'' \sum_{i=1}^{n} s_i} > 0$.

This implies that equation (3.25) can be rewritten as follows:

$$Cov(U', -p) + E(U')\frac{\partial f}{\partial x_i}\left(1 + E\frac{\partial s_i^{I=1}}{\partial x_i}\right)x_i + E\left[U'(\cdot)\sum_{j\neq i}^{n}\frac{\partial \pi_i^{I=1}}{\partial s_j^{I=1}}\frac{\partial s_j^{I=1}}{\partial x_i}\right] = 0. \tag{3.26}$$

The first and second term of (3.26) again represent the risk-hedging motive and negative price effect, respectively.[23] The third term of the FOC represents the strategic motive of forward selling and equals

$$E\left[U'(\cdot)\sum_{j\neq i}^{n}\frac{\partial \pi_i^{I=1}}{\partial s_j^{I=1}}\frac{\partial s_j^{I=1}}{\partial x_i}\right] = -E\left[U'(\cdot)\sum_{j\neq i}^{n}\left(P's_i\Theta + \frac{\partial f}{\partial Es_j}x_iE\Theta\right)\right], \tag{3.27}$$

where

$$\Theta \equiv \frac{P' + P''s_j}{(n+1)P' + P''\sum_{i=1}^{n} s_i}.$$

Expanding this term is far from trivial, since it depends on more than two random variables and, on top of that, some of these random variables enter in a rather complicated way. However, if we assume that $P'' = 0$ and that P' is non-random, as is the case with linear demand, Equation (3.27) reduces to

$$\begin{aligned} E\left[U'(\cdot)\sum_{j\neq i}^{n}\frac{\partial \pi_i^{I=1}}{\partial s_j^{I=1}}\frac{\partial s_j^{I=1}}{\partial x_i}\right] &= -E\left[U'(\cdot)\frac{(n-1)P'(s_i + x_i)}{n+1}\right] \\ &= -\frac{(n-1)P'}{n+1}Cov\left(U', s_i\right) - E[U']\frac{(n-1)P'(Es_i + x_i)}{n+1}, \end{aligned} \tag{3.28}$$

where we have used $\dfrac{\partial f}{\partial Es_j} = P'$.

We already obtained that $\dfrac{\partial U'}{\partial \epsilon} < 0$ and (under weak assumptions, see Footnote 22) $\dfrac{\partial s_i}{\partial \epsilon} > 0$, so the covariance term in (3.28) becomes negative. Now, given that

$$-E[U']\frac{(n-1)P'(Es_i + x_i)}{n+1} > 0,$$

the sign of the strategic effect is ambiguous. We get that (3.28) becomes positive as long as marginal utility and spot output are not highly negatively correlated, which at least holds for linear demand. If this is so, the strategic effect becomes positive and provides firms an additional incentive to sell forward.

[23]Note though that the price effect is less strong when forward positions are observed, as $|\partial s^{I=1}/\partial x_i| < |\partial s^{I=0}/\partial x_i|$.

3.5 Mean-variance approximation

A commonly used approach to study an agent's optimal behavior under risk aversion is the *mean-variance* model. Its attractiveness lies in its relative simplicity and its property to give linear demand functions for financial assets. Furthermore, as long as an agent's payoff is normally distributed the mean-variance approach yields identical results as when determining an agent's optimal choices under CARA utility. Unfortunately, in case the monetary payoff is not normally distributed, like in our framework, using the mean-variance model results in incorrect equilibrium conditions if agents maximize a CARA utility function. In this section, we study the magnitude of this error in the expected inverse hedge ratio, as this is our main variable of interest.

In order to find the size of the error, we first derive the equilibrium results under the mean-variance approach. Suppose firm i maximizes the mean-variance criterion:

$$W_i = E(\pi_i) - \frac{\rho_i}{2} V(\pi_i), \tag{3.29}$$

where ρ_i is again firm i's risk-aversion parameter and $E(\pi_i)$ and $V(\pi_i)$ are the expected value and variance of firm i's profit, respectively. Since we still assume that the realization of the demand shock takes place at the time the spot market opens, firms' spot strategies are the same as in equations (3.4) (when forward sales become observable) and (3.6) (when forward sales remain unobserved). This implies that, when moving one stage back, the expected profit of firm i can be written as

$$\begin{aligned} E(\pi_i) &= \gamma E\left(b(s_i^{I=1})^2\right) + (1-\gamma) E\left(b(s_i^{I=0})^2\right) + (f-c)x_i \\ &= \gamma b(s_0^{I=1})^2 + (1-\gamma) b(s_0^{I=1})^2 + \frac{\sigma^2}{b(n+1)^2} + (f-c)x_i, \end{aligned} \tag{3.30}$$

where

$$s_0^{I=1} = \frac{a + \sum_{j\neq i} c_j - nc_i - bx_i + b\sum_{j\neq i} x_j}{b(n+1)}$$

and

$$s_0^{I=0} = \frac{a + \sum_{j\neq i}^n c_j + b(n-1)\hat{x}_i/2 - nc_i - b(n+1)x_i/2 - b\sum_{j\neq i}^n \hat{x}_j}{b(n+1)}$$

are, respectively, the deterministic parts of firm i's spot strategy in case of observability and non-observability. The variance of the profit then becomes

$$\begin{aligned} V(\pi_i) &= E\left[(\pi_i - E(\pi_i))^2\right] = E\left[\gamma\left(\pi_i^{I=1} - E(\pi_i)\right)^2 + (1-\gamma)\left(\pi_i^{I=0} - E(\pi_i)\right)^2\right] \\ &= \gamma(1-\gamma)\left(b(s_0^{I=1})^2 - b(s_0^{I=0})^2\right)^2 \\ &+ \frac{4\sigma^2}{(n+1)^2}\left(\gamma(s_0^{I=1})^2 + (1-\gamma)(s_0^{I=0})^2\right). \end{aligned} \tag{3.31}$$

Substituting (3.30) and (3.31) into Equation (3.29) and maximizing the mean-variance criterion with respect to x_i yields the optimal forward sales for firm i:

$$x_i^{MV} = \frac{2(b\gamma(n-1)(n+1)^2 + 2(n+1-(n-1)\gamma)\rho_i\sigma^2)}{b(b(n+1)^4 - b\gamma(n^2-1)^2 + 4(1+\gamma+(1-\gamma)n)\rho_i\sigma^2)}\left(a + \sum_{j\neq i}^{n} c_j - nc_i - b\sum_{j\neq i}^{n} x_j\right).$$

The expected equilibrium inverse hedge ratio becomes

$$\Gamma_i^{MV} = \frac{(n+1)^2(n+1+(n-1)\gamma) + 4(n+1-(n-1)\gamma)\frac{\rho_i\sigma^2}{b}}{2(n-1)(n+1)^2\gamma + 4(n+1-(n-1)\gamma)\frac{\rho_i\sigma^2}{b}}. \tag{3.32}$$

The (mean of the) inverse hedge ratio under the mean-variance criterion has similar properties as the ratio obtained in our basic framework: it decreases in γ, ρ_i and σ^2, increases in b and goes down in n if γ is sufficiently large. To see the magnitude of the error from using the mean-variance framework, we subtract (3.32) from (3.11) to get

$$\begin{aligned}
\Delta_{\Gamma_i} &= \Gamma_i - \Gamma_i^{MV} \\
&= \frac{2((n+1-(n-1)\gamma)\frac{\rho_i\sigma^2}{b})^2}{(n+1)((n^2-1)\gamma + 2\frac{\rho_i\sigma^2}{b})((n-1)(n+1)^2\gamma + 2(n+1-(n-1)\gamma)\frac{\rho_i\sigma^2}{b})} \\
&\in (0, 1/2].
\end{aligned}$$

In case of no observability at all ($\gamma = 0$), the error becomes $1/2$, irrespective of the other parameter values. Our data reveals that this loss of accuracy seems to be quite large, given that the inverse hedge ratio is usually between 1 and 2. However, the size of the error goes down in γ. When there is full observability in the forward market ($\gamma = 1$), the accuracy loss becomes

$$\Delta_{\Gamma_i}(\gamma = 1) = \frac{8\left(\frac{\rho_i\sigma^2}{b}\right)^2}{(n+1)\left((n^2-1) + 2\frac{\rho_i\sigma^2}{b}\right)\left((n-1)(n+1)^2 + 4\frac{\rho_i\sigma^2}{b}\right)}. \tag{3.33}$$

It can be seen from Equation (3.33) that in case forward positions are observed with certainty, the error is smaller than $1/(n+1)$ and rapidly converges to zero when n becomes large (relative to $\rho_i\sigma^2/b$). For γ being strictly positive, we also notice that Δ_{Γ_i} increases in b and decreases in ρ and σ^2. Finally, to see how the loss of accuracy changes in the number of firms, we add to Figure 3.1 the relationship between the inverse hedge ratio and n for different values of γ under the mean-variance approach (displayed by the dashed curves in Figure 3.2). Figure 3.2 then shows that the error becomes smaller when more firms enter the market; this effect is especially apparent when the there is a high degree of observability.

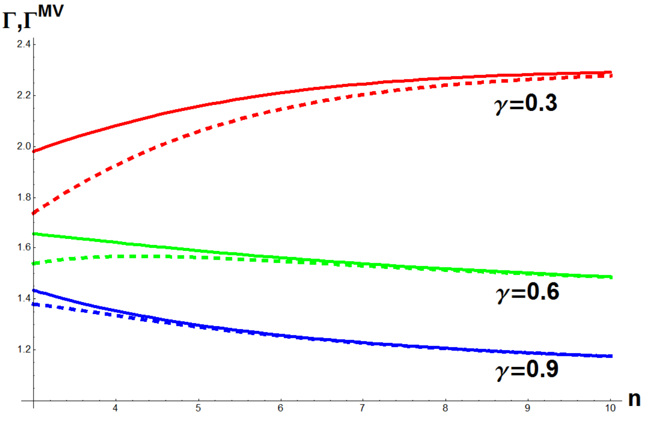


Figure 3.2: The inverse hedge ratio and the number of firms ($\rho_i = 4$, $\sigma^2 = 1$, $b = 1$)

We can compare our outcomes with the results obtained by Newbery (1988), who investigates the loss of accuracy when futures sales and prices are derived using the mean-variance model in case firm's income is the product of two normally distributed variables (i.e. a random spot price and random output). He shows that the error in computing the hedge ratio is quite large (near 30 percent) when producers are rather heterogeneous, the correlation between price and production is low and the futures market is biased. We notice that Newbery studies a model where a firm's total output is exogenously given, which implies that it is not affected by the firm's forward position. Conversely, when determining the error in the (inverse) hedge ratio in our case both the numerator and the denominator change. Furthermore, another difference between Newbery's analysis and our's is that he considers a competitive framework where producers cannot influence prices nor their rivals' strategies while our suppliers have market power.

3.6 Uncertain spot market

Until now, we have assumed that firms operate in the spot market in the absence of uncertainty. Therefore, we have modeled a market where firms observe the demand shocks before they decide how much gas to put in the spot market. Arguably, the demand may still remain uncertain at that moment. In such a case, firms cannot condition their spot strategies on the demand realizations. To see whether our results depend on this assumption, we now develop a model in which firms do not observe price shocks before the spot market opens. Of course, as before, the difference between the forward and the spot market is that at the forward stage the firms can lock-in a price for their forward quantities, while the price received for their spot quantities is random.[24]

In this new setting, a firm i that chooses its spot market strategy s_i aims at maximizing the expected utility from its spot market profits:

$$E[u(\pi_i^s)] = \int -e^{-\rho(p-c_i)s_i} f(\epsilon)d\epsilon.$$

To simplify the derivations, let us focus right away on the symmetric case where all firms are equally risk averse and have similar marginal costs of production. Given a forward strategy profile, when $I = 1$ the equilibrium spot market output of a firm i solves the first order condition:

$$s_i^{I=1} = \frac{a - c - bx_i - b(n-1)x_{-i}}{b(n+1) + \rho\sigma^2},$$

where x_i denotes firm i's forward sales and x_{-i} refers to the forward sales of firms other than i. In this case, the conditional reduced-form equilibrium profit is

$$\pi_i^{I=1} = ((b + \rho\sigma^2)s_i^{I=1} + \epsilon)s_i^{I=1} + (f - c)x_i,$$

where f, as above, denotes the forward price.

When forward positions of the rival firms are not observable, $I = 0$, the equilibrium spot market output of firm i is given by

$$s_i^{I=0} = \frac{(2b + \rho\sigma^2)(a - c - b(n-1)\hat{x}_{-i}) + b^2(n-1)\hat{x}_i - b(b(n+1) + \rho\sigma^2)x_i}{(2b + \rho\sigma^2)(b(n+1) + \rho\sigma^2)},$$

where $\hat{x}_i$ denotes rival firms' conjecture about the position of firm i, and $\hat{x}_{-i}$ refers to the conjectures about the forward positions of firms other than i. The equilibrium payoff in this case of no observability equals

$$\pi_i^{I=0} = ((b + \rho\sigma^2)s_i^{I=0} + \epsilon)s_i^{I=0} + (f - c)x_i. \tag{3.34}$$

At the forward market stage, a firm i picks its amount of forward sales x_i to maximize its expected utility. The equivalent to the FOC in equation (3.7) is given by

$$\int \rho e^{-\rho\pi}\Lambda(\cdot)f(\epsilon)d\epsilon = 0,$$

where

$$\Lambda(\cdot) \equiv -bx + \rho\sigma^2 s + (1-\gamma)\frac{b(bx - \rho\sigma^2 s - \epsilon)}{2b + \rho\sigma^2} - \gamma\frac{b(\rho\sigma^2 s - bx - (n-1)b(s+x) + \epsilon)}{b(n+1) + \rho\sigma^2}$$

[24]Notice that the results from maximizing CARA utility coincide with outcomes under the mean-variance method, since the a firm's payoff is now normally distributed.

and where we have imposed the symmetry of equilibrium strategies and the correctness of equilibrium conjectures conditions, i.e. $x_i = x_{-i} = \hat{x}_{-i} = \hat{x}_{-i}$. Solving for the equilibrium forward sales we obtain

$$x = \frac{(a-c)\left(2+\frac{\rho\sigma^2}{b}\right)\left(\gamma(n-1)+(n+1)\frac{\rho\sigma^2}{b}+\frac{\rho^2\sigma^4}{b^2}\right)}{b\Phi},$$

where

$$\begin{aligned}\Phi &\equiv \gamma(n-1)^2+(n+1)^2+(3(n+1)^2-2\gamma(n-1))\frac{\rho\sigma^2}{b}\\ &+ (n(n+5)-\gamma(n-1)+3)\frac{\rho^2\sigma^4}{b^2}+(n+1)\frac{\rho^3\sigma^6}{b^3}.\end{aligned}$$

Building on this expression, we can state the following result.

Proposition 3.2 *Suppose that firms do not observe the demand shocks before the spot market opens. Then the inverse hedge ratio of a firm i is deterministic and given by*

$$\hat{\Gamma} \equiv \frac{\gamma(n-1)+(n+1+\frac{\rho\sigma^2}{b})(1+3\frac{\rho\sigma^2}{b}+\left(\frac{\rho\sigma^2}{b}\right)^2)}{(2+\frac{\rho\sigma^2}{b})(\gamma(n-1)+\frac{\rho\sigma^2}{b}(n+1+\frac{\rho\sigma^2}{b}))}. \tag{3.35}$$

The inverse hedge ratio $\hat{\Gamma}$ is independent of the demand intercept parameter a and of the firm marginal cost c, increases in the demand slope parameter b, decreases in ρ and in σ^2, decreases in γ and is (weakly) monotonically decreasing in the number of firms n.

Compared to the inverse hedge ratios in Proposition 3.1, we see that when spot market strategies cannot be adapted to accommodate the demand shocks, inverse hedge ratios are always (weakly) decreasing in the number of players. The intuition behind this result is as follows. As before, the incentives of a firm to sell forward are governed by a price effect, a risk-hedging effect and a strategic effect. The price effect is again constant in the number of firms. Since firms cannot adapt their spot strategies to demand fluctuations, the risk-hedging effect turns out to be independent of the number of firms too. In fact, when forward positions are not observable, the inverse hedge ratios are constant in the number of players:

$$\hat{\Gamma}(\gamma=0) = 1+\frac{1}{2}\left(\frac{1}{\frac{\rho\sigma^2}{b}}+\frac{1}{2+\frac{\rho\sigma^2}{b}}\right).$$

When the forward market is not totally opaque so that the positions of the firms are somewhat observable, the strategic commitment role of selling forward leads firms to sell a higher output in the forward market the higher the number of players is. As a result, by the latter effect, inverse hedge ratios fall in n. When the market is fully transparent, in fact we obtain

$$\hat{\Gamma}(\gamma = 1) = 1 + \frac{1 + \frac{\rho\sigma^2}{b}}{n - 1 + (n+1)\frac{\rho\sigma^2}{b} + \left(\frac{\rho\sigma^2}{b}\right)^2},$$

which clearly decreases in n.

3.7 Concluding remarks

This chapter has proposed a methodology to investigate whether oligopolistic firms sell futures for strategic reasons, for risk-hedging motives, or for both. Our empirical test builds on a theoretical model of the interaction of risk-averse firms that compete in futures and spot markets. We find that the effects of an increase in the number of players on the equilibrium hedge ratio depend on the strategic role played by forward contracts. If forward sales play no strategic role whatsoever, the inverse hedge ratio increases as more firms enter the market; otherwise, the hedge ratio decreases. Firms hedge less if demand is very elastic and, as expected, more risk averse firms have a greater propensity to hedge. These results serve to structure the empirical research conducted in the next chapter.

Addressing the question whether firms trade forward for strategic purposes is relevant from a social point of view. To increase transparency in energy forward markets, policymakers all over the world have facilitated the creation of organized exchanges where energy futures can be traded. The costs of operating a futures market are non-negligible even in a time where virtual market places have displaced the more traditional physical hubs. In fact, personnel and ICT costs, along with the insurance and financial costs of dealing with default and other risks involved may render a marketplace unprofitable. For instance, ENDEX, the Dutch exchange for power and gas derivatives, has been making losses for 5 out of its 6 or 7 years of existence.[25] When (partly) financed by public funds, loss-making exchanges constitute a loss for society. If it turns out that firms trade forward contracts strategically, subsidizing a futures market may be validated if futures trade is relatively transparent and therefore has high commitment value for firms.

Forward markets exist for a number of commodities, including electricity, natural gas, emission trading permits, copper, iron ore, aluminium, steel etc. Though in

[25] At the end of 2009, ENDEX was taken over by the APX Group, which owns various platforms for spot trading of natural gas and electricity in the NL, Belgium and the UK.

the following chapter we apply our model to the natural gas market in the Netherlands, we believe the general message of this chapter is broader. Our insights, and in particular our methodology to address the question whether firms trade futures for strategic motives, should be applicable to other markets where firms have significant market power.

3.A Appendix

Proof of Proposition 3.1. It is clear that Γ_i depends neither on c_i nor on a. Given that

$$\frac{\partial \Gamma_i}{\partial \rho_i} = -\frac{(n+1-\gamma(n-1))^2 b\sigma^2}{(b\gamma(n^2-1)+2\rho_i\sigma^2)^2} < 0,$$

the inverse hedge ratio decreases as the firm is more risk averse. From this it readily follows that inverse hedge ratios decrease in the uncertainty of the demand parameter and increases in slope of the demand. Since

$$\frac{\partial \Gamma_i}{\partial \gamma} = -\frac{(n-1)(b(n+1)^2+2\rho_i\sigma^2)^2}{2(n+1)(b\gamma(n^2-1)+2\rho_i\sigma^2)^2} < 0,$$

the inverse hedge ratio decreases in the probability forward positions are observed.

Finally, we notice that

$$\frac{\partial \Gamma_i}{\partial n} = \frac{2b(n+1)((n+1)^2+(n-1)^2\gamma^2-2\gamma n(n+1))\rho_i\sigma^2 - b^2\gamma(n+1)^4-(2\rho_i\sigma^2)^2}{(n+1)^2(b\gamma(n^2-1)+2\rho_i\sigma^2)^3}.$$

Note that $\partial\Gamma_i/\partial n$ is differentiable w.r.t. γ, which implies that $\partial\Gamma_i/\partial n$ is continuous in γ. Next, we observe that

$$\left.\frac{\partial \Gamma_i}{\partial n}\right|_{\gamma=0} = \frac{b(n+1)}{2\rho_i\sigma^2} > 0$$

and

$$\left.\frac{\partial \Gamma_i}{\partial n}\right|_{\gamma=1} = -\frac{1}{(n+1)^2} - \frac{4b^2 n}{(b(n^2-1)+2\rho_i\sigma^2)^2} < 0,$$

for all $n \geq 2$, $b > 0$, $\rho_i > 0$ and $\sigma^2 > 0$. Given that $\partial\Gamma_i/\partial n$ is continuous in γ, this implies that $\partial\Gamma/\partial n = 0$ for at least one $\gamma \in (0,1)$. Further, $\partial\Gamma/\partial n = 0$ has two solutions for γ, denoted by $\tilde{\gamma}(n)$ and $\tilde{\gamma}_2(n)$:

$$\tilde{\gamma}(n) \equiv \frac{b^2(n+1)^4+4bn(n+1)^2\rho_i\sigma^2+4\rho_i^2\sigma^4-(b(n+1)^2+2\rho_i\sigma^2)\sqrt{Z}}{4b(n-1)^2(n+1)\rho_i\sigma^2}$$

and

$$\tilde{\gamma}_2(n) \equiv \frac{b^2(n+1)^4+4bn(n+1)^2\rho_i\sigma^2+4\rho_i^2\sigma^4+(b(n+1)^2+2\rho_i\sigma^2)\sqrt{Z}}{4b(n-1)^2(n+1)\rho_i\sigma^2},$$

where $Z = b^2(n+1)^4+4b(n+1)^2(2n-1)\rho_i\sigma^2+4\rho_i^2\sigma^4$. Now for all $n \geq 2$, $b > 0$, $\rho_i > 0$ and $\sigma^2 > 0$, we have:

$$\begin{aligned}
\tilde{\gamma}_2(n) > &\quad \frac{2(b(n+1)^2+2\rho_i\sigma^2)^2+4b(n-1)(n+1)^2\rho_i\sigma^2}{4b(n-1)^2(n+1)\rho_i\sigma^2} \\
> &\quad \frac{2(b(n+1)^2+2\rho_i\sigma^2)^2+4b(n-1)(n+1)^2\rho_i\sigma^2}{4bn(n-1)(n+1)\rho_i\sigma^2} \\
= &\quad \frac{n+1}{n} + \frac{(b(n+1)^2+2\rho_i\sigma^2)^2}{2bn(n-1)(n+1)\rho_i\sigma^2} \\
> &\quad 1.
\end{aligned}$$

Since $\tilde{\gamma}_2(n) > 1$ and $\partial\Gamma_i/\partial n = 0$ for at least one $\gamma \in (0,1)$, it must be true that $\tilde{\gamma}(n) \in (0,1)$. Now, because $\left.\dfrac{\partial\Gamma_i}{\partial n}\right|_{\gamma=0} > 0$ and $\left.\dfrac{\partial\Gamma_i}{\partial n}\right|_{\gamma=1} < 0$ and by continuity in γ, we have $\dfrac{\partial\Gamma_i}{\partial n} < 0$ if $\gamma < \tilde{\gamma}(n)$ and $\dfrac{\partial\Gamma_i}{\partial n} > 0$ if $\gamma > \tilde{\gamma}(n)$. Finally, imposing symmetry across firms we can readily obtain the equilibrium forward sales of a firm:

$$\hat{x} = \frac{2(a-c)(n^2-1)\gamma + 2\frac{\rho\sigma^2}{b}}{(n+1)((n+1)^2 + \gamma(n-1)^2 + 2(1+\gamma-n(\gamma-3))\frac{\rho\sigma^2}{b})}.$$

Observing the expression in Equation (3.10), it is clear that the variance of the inverse hedge ratio is $\sigma^2/b^2(n+1)^2\hat{x}^2$, which clearly decreases in a, ρ and σ^2, and increases in c, b and in γ. ■

Chapter 4

Do firms sell forward for strategic reasons? An application to the wholesale market for natural gas*

4.1 Introduction

In the previous chapter, we have developed an empirical strategy to test whether oligopolistic firms use forward contracts for strategic motives, for risk-hedging, or for both. We have shown this empirical strategy is based on the the properties of a firm's expected inverse hedge ratio. Particularly, the identification of the strategic motive to sell forward relies on variation in the number of participants in the industry.

In this chapter, we apply this strategy to the Dutch wholesale market for natural gas. In contrast to restructured markets elsewhere, the Dutch natural gas market is one where forward contracts have not been forced upon the producers and wholesalers by the regulator. This is important because otherwise it would be difficult to learn whether the market by itself provides the players with the necessary hedging and commitment opportunities.[1]

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*This chapter is based on van Eijkel and Moraga-González (2010).

[1] Our empirical strategy is therefore built upon a theoretical framework where the supply of forward contracts depends on the firms' incentives and is thus *endogenous* to the model. This is in contrast to situations where regulators impose forward obligations on large energy suppliers. One

Our data set consists of a fairly large fraction of all (forward, spot and speculative) trades conducted at the Dutch gas hub Title Transfer Facility (TTF), from April 2003 until June 2008.[2] The TTF is a virtual trading hub that offers market participants the possibility to transact 'entry-paid gas', both on a forward and spot basis.[3] At the TTF, gas can be traded at high speed before it leaves the pipeline system at a specific exit point. This has triggered the entry of new players into the Dutch market and the creation of centralized exchanges where standardized contracts change hands. Since we also have data on the number of active wholesalers at the TTF, we can exploit this information to estimate the restrictions on the inverse hedge ratios imposed by the theoretical model. Despite the recent emergence of gas exchanges, the bulk of TTF trade is conducted over-the-counter, either via bilateral negotiations or through brokers.[4] Since there is a widespread belief that transactions in the OTC market are not as visible as in centralized exchanges, the question arises whether the TTF provides gas wholesalers the possibility to trade forward contracts for strategic purposes.

Our results lend support to the hypothesis that wholesalers in the Dutch gas industry find opportunities to sell on a forward basis for strategic reasons. Given that the lion's share of TTF trade takes place in the OTC market, we think this is an important result. OTC markets are often criticized for being relatively opaque, impeding the development of efficient markets where prices contain a high level of information about market conditions.[5] However, for the strategic commitment value of forward trading to exist the contract market has to be relatively transparent. Hence, at least for the Dutch gas industry it seems that at the wholesale level OTC

example of this dictated contractual commitment is the obligation for dominant firms in electricity and gas markets to auction off part of their production by means of virtual power plants (VPPs) and gas release programs, respectively. Fabra and de Frutos (2009) show that these energy release programs are pro-competitive as long as they reduce asymmetries between firms. These types of forward contract commitments however do not seem to play a significant role in the Dutch natural gas market.

[2]We use information on churn rates (i.e. information on the fraction of speculative trades) to construct the inverse hedge ratios concerning the actual deliveries of natural gas.

[3]Entry-paid gas is gas that is already injected into the Dutch gas transmission grid or for which transportation capacity has already been booked.

[4]The Dutch exchanges APX (spot) and ENDEX (futures) came into existence only after 2005, which implies that for the first few years of our sample period all TTF gas has been traded in the OTC market. Gradually, the exchanges have gained some market share over time and for the last months in our data set the share of exchange trade as a percentage of total TTF trade was around 8 percent.

[5]For instance, the non-transparency of OTC trade has often been blamed for exacerbating the recent financial crisis (see e.g. Acharya and Bisin, 2010 and Duffie, Li and Lubke, 2010).

transactions convey sufficient information about firms' forward decisions. Moreover, we also observe that the strategic motive has become somewhat more important over time which may indicate that the TTF has gained in transparency. Another interpretation of this result is that there exists a learning effect, that is, market players have become more competent to infer from price changes what is happening in the market.[6]

Surprisingly, we find no statistical evidence that in the Dutch gas market wholesale firms hedge their output for risk-hedging reasons. As can be read in the previous chapter, one potential problem that makes it more complicated to estimate the degree of risk aversion precisely is that without further information on spot price volatility, one cannot identify the risk aversion parameter separately from the variability of the (spot) price shocks. To address this issue, we run a regression using data on the volatility of spot prices. Still, we do not find that firms use forward contracts to hedge against price shocks in the spot market.

This result becomes even more interesting when comparing it to insights from research on risk-hedging in electricity industries. Amongst others, Longstaff and Wang (2004) and Bessembinder and Lemmon (2006) provide empirical evidence that market participants in power markets do trade on a forward basis to hedge against spot price shocks. Bessembinder and Lemmon use data on the Pennsylvania, New Yersey and Maryland (PJM) and the California Power Exchange (CALPX) wholesale electricity markets to test the hypotheses derived from their theoretical model on forward trading and pricing. They find some preliminary evidence that in periods with higher demand, more price variability and greater price skewness forward premia are higher than at other times. Having a more extensive data set at their disposal than Bessembinder and Lemmon, Longstaff and Wang also conclude that for the PJM power market intertemporal changes in the forward premia are driven by market risk fundamentals.

One could think that the different attitude towards risk across the two different industries is due to the allegedly higher volatility in electricity prices compared to price variability in the gas market. The explanation that is usually put forward to

[6] There is some further empirical evidence that forward contracting has a pro-competitive effect (Green, 1999; Wolak, 2000; Fabra and Toro, 2005; Hortaçsu and Puller, 2008; Bushnell, Mansur and Saravia, 2008). These papers have focused on electricity markets where forward contracts have often been imposed by regulators and can therefore be considered exogenous to the equilibrium process. As already being pointed out, we deal instead with a market where forward contracts are endogenous which enables us to see whether the market by itself provides the necessary incentives to the firms to engage in strategic contracting.

defend this claim is the non-storable nature of electricity, which eliminates the value of holding inventories to accommodate demand fluctuations. As a result, sudden price shocks are more likely to occur. Though in principle natural gas can be stored, we however also observe significant volatility in gas prices, at least at those market levels where the link to the oil price has been removed and prices have become more in line with changes in supply and demand conditions. A reason for this could be that the opportunities to store gas are limited and relatively costly, so that for its most part production, delivery and consumption take place contemporaneously.[7] As we will see later in this chapter, also at the TTF market participants are frequently confronted with quite severe price shocks.[8] This suggests that the degree of price variability in the Dutch gas market cannot explain the lack of risk-hedging incentives for wholesale firms in this market. Later in this chapter, we will discuss in somewhat more detail that the most plausible reason for the fact that we do not find a significant hedging incentive is that the strategic motive is present. Our results suggest that when firms sell forward for strategic reasons, the residual volatility in the market is small so risk-hedging plays no longer a fundamental role.

This chapter is structured as follows. The next section gives a short overview of the Dutch wholesale market for natural gas, where we particularly look at the role of the TTF in this market. In Section 4.3, we discuss the data set we use for our empirical study and provide some descriptive statistics of the data. Section 4.4 is the core of this chapter and contains the main empirical analysis. Then in Section 4.5 we investigate a few further issues, most of them being merely robustness checks. This chapter ends with some concluding remarks. The Appendix provides some more information about the different types of contracts that are traded at the TTF.

4.2 The Dutch wholesale market for natural gas

We use data from the Dutch wholesale market for natural gas. For the purpose of this chapter, these data are very useful because forward contracts have not been imposed by the regulator so they can be considered endogenous to the market process.

As in many other countries, traditionally, gas supply in the Dutch wholesale

[7] Regnier (2007) shows that in recent years, the price volatility of fuel gas in the U.S. is actually much higher than the variability in electricity prices.

[8] To provide some first insight in the price fluctuations on the TTF, we note that in the first two days of March ’05 the spot price index was around 27 €/MWh, after which it increased to 31 €/MWh on the third day and rose further to 51 €/MWh on the 4th of March. On the sixth trading day of March ’05 the gas price index was back on a low level of 18 €/MWh.

market was controlled by a single integrated network company –the NV Nederlandse Gasunie.[9] Gasunie did not only own the transmission network, but also had control over the national distribution pipelines and the gas supplies. Gas originated from the Dutch gas fields or was imported from foreign producers.[10] Gasunie sold the gas to industrial customers and distribution companies.

Market deregulation in the Netherlands started back in the late 1990s with the *Price Transparency Directive*, but gained full momentum with the *First Gas Directive* of the European Union in 1998. This ruling abolished import monopolies, forced the opening of markets and imposed the accounting unbundling of vertically integrated network companies. The *Second Gas Directive* of the European Union in 2003 furthered the liberalisation process by requiring full market opening, regulated third party network access, regulated or negotiated access to storage and legal unbundling of integrated network companies. As a consequence of this directive, Gasunie was split up into two independent companies: Gas Transportation Services (GTS), which controls the national transmission network, and Gasterra, which is engaged in gas wholesaling. The second directive also required the creation of national energy regulators.

To attain a well-functioning wholesale gas market in The Netherlands, the Title Transfer Facility (TTF) was created in 2003. The TTF is a virtual trading hub that offers market parties/shippers the possibility to buy and sell gas that is already injected into the national gas transmission grid, or for which transportation capacity has already been booked. Thanks to the TTF gas can easily change hands before it is extracted at a specific local or export exit point. This triggered the entry of new players into the Dutch market.[11] The TTF made the emergence of gas exchanges possible. APX Gas NL B.V. runs an exchange for spot contracts. At APX, market parties can trade standardized contracts for gas delivery one day ahead and within

[9]Gasunie was a joint venture between De Staatsmijnen (DSM), Shell, Esso and the Dutch State.

[10]The sources of supply are similar in recent days. In 2008 there were 35 production fields and 17 import entry points (GTS, 2008). The bulk of Dutch gas production takes place in the Groningen gas field. After the discovery of this field in 1959, the Nederlandse Aardolie Maatschappij (NAM), a joint venture between Shell and Esso, obtained a governmental concession to explore and exploit this gas field. The NAM was however obliged to sell all the gas extracted from the Groningen field (and other small fields in the Netherlands) to Gasunie.

[11]New players include new wholesale companies such as Gaz de France, BP, EON, Gazprom, RWE, Statoil, Total, etc., as well as new financial players such as JP Morgan, The Royal Bank of Scotland, BNP Paribas, Morgan Stanley, Citygroup, Barclays Bank, etc. By contrast, there has not been much entry of new retailers in the TTF. What has happened is that the existing distribution companies (Essent, Nuon, Eneco, GDF Suez, etc.) have become active outside their traditional territories as well as abroad.

the same day. ENDEX N.V. runs an exchange for a variety of gas futures contracts.[12] At the end of 2008 ENDEX N.V. was taken over by APX B.V., which is also the owner of APX Gas NL B.V.

The TTF allows gas buyers in the wholesale market to hold a portfolio of different types of gas products. Long-term take-or-pay contracts used to be the dominant contract type in the industry. Nowadays a buyer can buy gas on a short-term basis at the trading hub. Since gas demand typically has a seasonal pattern, firms gain in flexibility by participating in this new market. Over the years we have witnessed an increase in volumes traded at the TTF. By 2008, a substantial share of 20 percent of gas that flows through the GTS transport system reached the trading hub. The Dutch regulator expects that in the future the TTF will be sufficiently liquid so as to offer market participants all the hedging opportunities they need.[13]

4.3 Data

Our data set consists of a substantial fraction (approximately 75 percent) of all forward and spot contracts traded at the Dutch TTF for the period from April 2003 until June 2008. These data were provided by the company ICIS Heren.[14] In addition, we obtained data from the transport operator GTS on the number of wholesalers active every month, on the daily churn rates and on the total daily volumes.[15] Unfortunately, we do not have information on the identity of the trading partners so we are unable to perform the analysis at the firm level. As explained earlier, if firms do not differ much in their aversion to risk, they will hedge in a similar fashion, even if there exist significant cost differences across them.

Transactions can be either facilitated by brokers, or exchange-based, or the out-

[12]The minimum length of a contract is one month and the maximum length is one (calendar) year. Contracts can range from a month ahead to three years ahead of delivery. In Appendix 4.A we provide more details on the types of contracts traded at the TTF.

[13]Most of the TTF-traded gas is high-calorific, which is gas that is mostly used for industrial and exporting purposes. High-calorific can also be converted into low-calorific gas, which is the gas intended for domestic residential usage.

[14]ICIS Heren (http://www.icis.com/heren/) is a leading specialized information provider for energy markets. The company publishes price assessments, indices, news and analysis for various energy markets. ICIS Heren gathers daily price and quantity information from brokers and directly from the participants in the industry via telephone calls.

[15]The participants in the industry must make ‘nominations’ to the transport operator once the gas changes hands. In this way, the transport operator receives the necessary information to compute total traded volumes and the churn rates. Using the data on total volumes delivered at the TTF, we estimate that our data contains well above 50 percent of the total market.

come of bilateral negotiations. All these three types of transactions are included in our data set, but we cannot distinguish between them in the sense that we cannot tell whether a transaction is over-the-counter or has occurred at the centralized exchange ENDEX. As said before, there are several types of contracts traded at TTF. For a given trading day, we are interested, on the one hand, in the total volume of gas delivered and, on the other hand, in the amount that has been sold forward. To compute all the gas delivered in a given date, we sum all the quantities specified in different contracts that call for delivery on such a day. To compute how much of this volume is contracted forward, we need to make an assumption about the nature of uncertainty in this market. We make the assumption that only day-ahead and within-day contracts form the spot market so the rest of the contracts are considered futures contracts.[16]

To be clear, suppose that in year 2003, three products have been traded: (i) a forward contract traded on November 3 that calls for delivery of 720 MegaWatt hour (MWh) each day in December 2003, (ii) a day-ahead contract traded on December 6, 2003 for delivery of 4,320 MWh the next day, and (iii) a spot contract traded on December 20, 2003 for delivery of 1,440 MWh the same day. Then, except for two days, December 7 and 20, for each day in December 2003 the delivery volume is 720 MWh. On December 7, the total delivery volume equals (720+4,320=) 5,040 MWh while on December 20, the delivery volume is (720+1,440=) 2,160 MWh. As a result, the hedge ratio is 1 for all days of December 2003 except for December 7, with an inverse hedge ratio of 8, and December 20, with an inverse hedge ratio of 3.

One difficulty of the data at hand is that a substantial part of the transactions we observe concerns contracts that are traded with or between speculators. Since financial traders must have zero net positions before delivery, many of the contracts we see are re-trades and do not involve volumes that are finally brought to the market. Fortunately, we can deal with this issue using data on churn rates (net-to-gross-volume ratios). Churn rates are reported by GTS. These rates do not distinguish between forward trades and spot market trades. Obviously, actual churn rates for spot market transactions are much lower than those corresponding to forward trades, since the

[16]We have discussed the validity of this assumption with participants in this industry. At the margin, the main driver of demand is temperature. Therefore, if any, the main source of uncertainty here is due to temperature fluctuations. According to the participants, the weather predictions one day ahead are quite accurate. Moreover, within-day and day-ahead deals are conducted at one and the same exchange (APX) while contracts with longer duration are traded on a different exchange (ENDEX). This suggests that the industry considers day-ahead and within-day contracts as being of similar type.

length of time to resell contracts is rather short in the spot market. In what follows, we assume forward transactions have a churn rate equal to the churn rate reported by GTS; for spot market trades, we assume the churn rate equals one.[17] Table 4.1 provides some descriptive statistics of our data and Figure 4.1 displays the forward sales adjusted for the churn rate, as well as the spot market sales.[18]

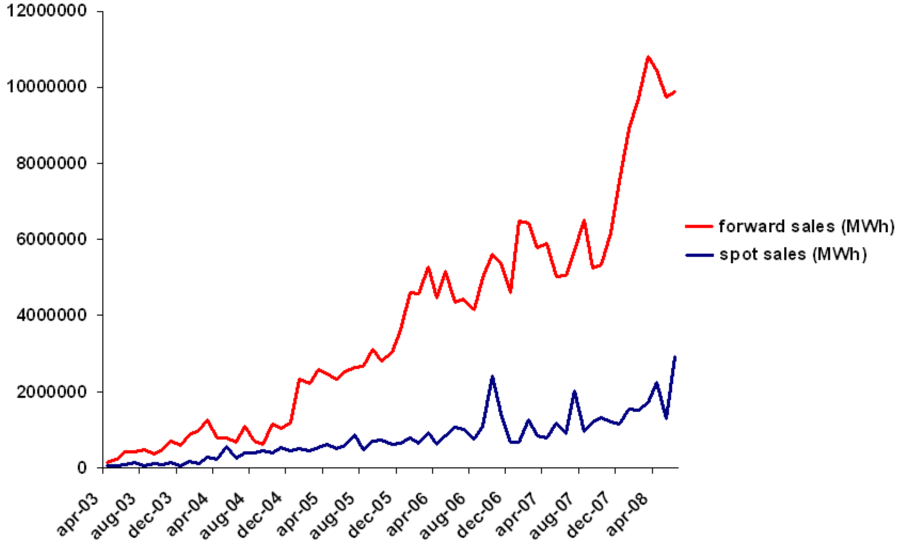

Figure 4.1: Forward market and spot market sales

The descriptive statistics reveal four interesting aspects of the data. First, volumes traded at the TTF have gone up a great deal.[19] In fact, by 2008 the TTF

[17]In different words, we are assuming speculators do not take positions during the time the spot market is open. If we had information on the identity of the traders, we could check the validity of this assumption.

[18]Besides data on traded volumes, Table 4.1 also contains information on forward prices and spot prices. The forward price indices we report concern monthly contracts. We compute four different forward price indices: the price index obtained using all transactions that take place (1) more than one month before the month of delivery; (2) in the first half of the month preceding delivery; (3) in the last half of the month before delivery (4) in the last two days before delivery. In Table 4.1, we only report the index for monthly contracts traded in the first half of the month preceding the delivery month. The other indices show a very similar pattern. Spot prices are determined by computing an index for all the day-ahead deals included in our data set.

[19]Currently net volumes in the TTF are approximately equal to the total supplies of natural gas to large industrial users in The Netherlands, including the electricity generating companies. This is about 20% of the total amount of gas that enters the Dutch pipeline system (about 43% of the gas that enters the Netherlands is ‘transit’ gas, i.e., exports to other countries).

Year	Variable	Min	Max	Mean	Std. Dev.
2003	Wholesalers	9	11	10.11	0.93
	Wholesalers 80%	4	6	5.22	0.67
	Spot (GWh)	63.96	145.54	93.25	34.05
	Forward (GWh)	193.92	1646.64	856.91	491.32
	Churn rate	1.42	2.67	1.92	0.41
	Net forward (GWh)	136.71	712.28	419.61	172.42
	Inv. hedge ratio	1.11	1.49	1.26	0.12
	Forward price	10.10	15.09	11.56	1.88
	Spot price	8.42	14.26	11.08	2.03
2004	Wholesalers	11	15	13	1.48
	Wholesalers 80%	5	8	6.5	0.90
	Spot (GWh)	133.44	561.84	353.82	137.08
	Forward (GWh)	1512	3494.02	2455.11	638.83
	Churn rate	2.04	3.15	2.65	0.37
	Net forward (GWh)	624.38	1281.44	932.05	220.23
	Inv. hedge ratio	1.14	1.73	1.4	0.19
	Forward price	10.34	14.78	12.06	1.60
	Spot price	10.67	14.88	11.84	1.30
2005	Wholesalers	14	20	17.17	1.90
	Wholesalers 80%	7	10	8.58	0.9
	Spot (GWh)	433.92	866.88	599.64	126.26
	Forward (GWh)	6479.28	10911.60	8322.37	1183.82
	Churn rate	2.69	3.34	3.09	0.18
	Net forward (GWh)	2220.24	3622.44	2699.18	397.34
	Inv. hedge ratio	1.18	1.33	1.22	0.04
	Forward price	13.48	22.09	16.32	2.61
	Spot price	14.20	23.91	16.66	2.99
2006	Wholesalers	21	24	22.42	1.24
	Wholesalers 80%	10	11	10.25	0.45
	Spot (GWh)	621.60	2397.68	1022.42	487.18
	Forward (GWh)	13030.15	19472.21	15788.77	2150.13
	Churn rate	2.83	4.23	3.29	0.41
	Net forward (GWh)	4166.79	5615.75	4805.13	471.61
	Inv. hedge ratio	1.14	1.43	1.21	0.08
	Forward price	19.35	27.35	22.65	2.92
	Spot price	14.18	28.07	20.82	3.95
2007	Wholesalers	25	28	25.67	0.98
	Wholesalers 80%	11	14	12.75	1.06
	Spot (GWh)	684.34	2027.78	1130.29	353.96
	Forward (GWh)	18279.17	26240.35	22141.36	2734.63
	Churn rate	2.84	4.66	3.77	0.56
	Net forward (GWh)	5033.53	7520.37	5934.65	732.21
	Inv. hedge ratio	1.11	1.35	1.19	0.07
	Forward price	10.03	25.56	14.99	5.28
	Spot price	9.16	22.87	14.71	4.93
2008	Wholesalers	28	29	28.67	0.52
	Wholesalers 80%	12	12	12	0
	Spot (GWh)	1310.18	2910.58	1875.08	603.48
	Forward (GWh)	28625.40	35767.02	33389.21	2531.02
	Churn rate	3.22	3.57	3.37	0.12
	Net forward (GWh)	8900.29	10797.62	9911.70	659.24
	Inv. hedge ratio	1.13	1.29	1.19	0.06
	Forward price	21.79	25.94	24.26	1.57
	Spot price	22.73	26.64	24.70	1.44

Notes: Year 2003 averaged over 9 months. Year 2008 over 6 months.

Table 4.1: Descriptive Statistics (monthly averages)

became the second largest gas trading hub in Europe, both in terms of traded volume and net (physical) flow.[20] A first explanation for this phenomenon is that, as compared to for example the Zeebrugge hub in Belgium, the TTF benefits from the absence of third-party access exemptions to the Dutch pipeline system. A second issue is that the entry/exit points to the Dutch pipeline system are well interconnected and this allows for the TTF to function as a virtual hub, which relaxes the physical constraints imposed by the capacities of the various pipelines. Finally, adding to the attractiveness of the Dutch trading hub as compared to signing long-term contracts is the opening of the BBL pipeline in 2006, which connects the Netherlands and the U.K. The BBL pipeline allows TTF-traded gas to be shipped to the U.K. and this brings TTF prices down and more in line with U.K. prices.

A second aspect of the data is that a significant part of the total volume traded at the TTF is hedged (between 60 and 90 %). It is also remarkable that the hedge ratio has increased over time but, by no means, it has changed by the order of magnitude the volumes have changed. Furthermore, we note that the standard deviation of the inverse hedge ratio seems to have gone down over the sample period. The latter two observations appear to be in line with our model of firm behavior (inverse hedge ratios are mean independent of the strength of the demand parameter and have a standard deviation negatively correlated with it, see Proposition 3.1). Finally, it can be seen from Table 4.1 that forward prices and spot prices are closely linked, though the former are in general somewhat higher than the latter.[21]

As discussed earlier, identification of the key parameters of the model requires variation in the number of wholesalers operating in the market. The TTF is a market where in fact there has been a steady increase in the number of participants. However, from our data on transactions we cannot extract the number of wholesalers since we do not have information on the identity of the traders engaged in a transaction. We obtained data on the number of active wholesalers in a given month from the GTS.[22] Since some wholesalers are probably very small and have no market power

[20] The National Balancing Point (NBP) in the U.K., introduced in 1996, has long since been the most liquid hub in Europe.

[21] Using the four different forward price indices, we perform an ANOVA test of the null hypothesis that spot and forward prices are statistically similar to each other. For three out of the four forward price indices, the hypothesis cannot be rejected (the only index that appears to be significantly different than the spot price index is the one computed from transactions that take place longer than a month before delivery).

[22] To conduct transactions at the TTF, participants must first subscribe with the TTF either as wholesalers, industrial customers, retailers or pure traders. The subscription can be made for a single gas month or for a full calendar year. Subscribing involves the payment of some fixed fees and, in addition, traders have to pay some variable fees for the volumes traded.

whatsoever, we also asked for the number of active wholesalers making up for 60 and 80 percent of total delivery. Figure 4.2 shows the evolution of the total number of active wholesalers, as well as the development of the number of suppliers that account for more than 60 and 80 percent of the gas delivered in the TTF. Note that not only more gas wholesalers have entered the TTF in the period under analysis, but also that, as time has elapsed, the 60 and 80 percent market share has become distributed over more firms. This suggests that the supply of gas has become less concentrated in the Netherlands.

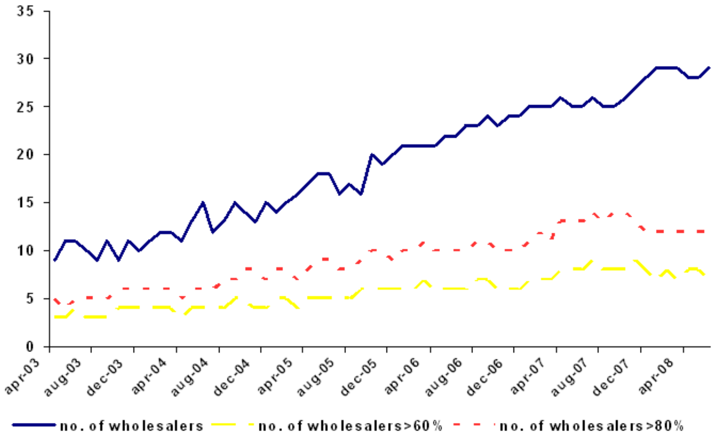

Figure 4.2: Number of wholesalers active at TTF

Given the monthly nature of our data on the number of active wholesalers, we compute aggregate monthly delivery forward and spot volumes and conduct the analysis using 63 monthly observations. To get a first impression of whether gas wholesalers trade forward contracts for strategic reasons, we pool together the months in which the number of active suppliers that serve 80% of the market is the same and compute the average hedge ratio for those months. We then regress the hedge ratio on a constant and on the number of wholesalers. Figure 4.3 displays the relation between the number of wholesalers trading at the TTF and the average ratio of interest. The dots in the figure represent the average ratio for a given number of wholesale firms in our data set, while the dashed line shows the estimated relation between the number of wholesalers and the inverse hedge ratio. The results of the regression indicate that this relation is negative, which, according to the theoretical model, suggests that forward contracts are used as strategic instruments.[23] Since

[23]More precisely, we estimate by OLS the model $\hat{\Gamma}_n = \alpha + \beta n + u_n$, where $\hat{\Gamma}_n$ is the average

this regression does not allow us to learn the extent to which the players' positions are observed, we proceed by estimating the model structurally.

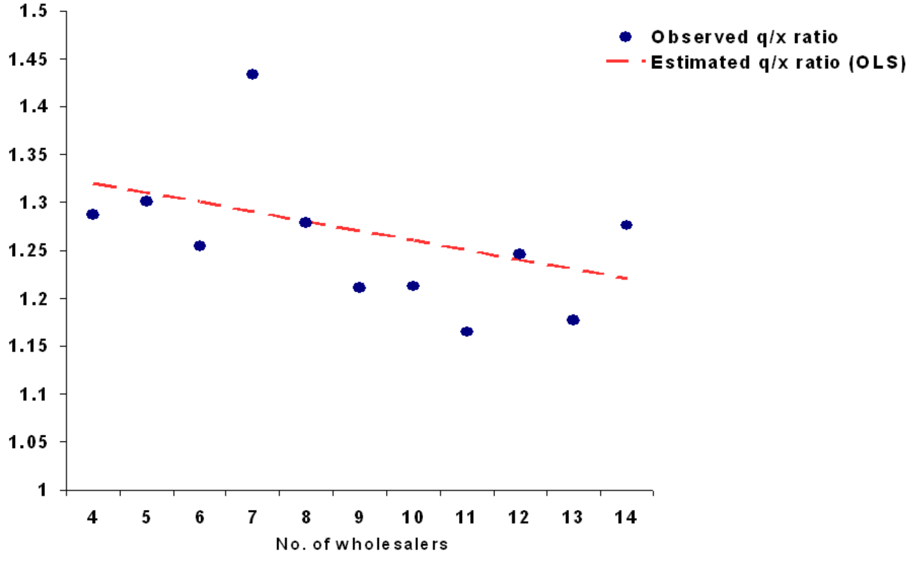

Figure 4.3: Inverse hedge ratio and the number of wholesalers

4.4 Results

The relation to be estimated can be written as (see Equation (3.15))

$$\frac{n_t+1}{n_t}\sum_{i=1}^{n} s_{it} = \frac{n_t+1}{n_t}\left(\Gamma(n_t,\gamma,\lambda)-1\right)\sum_{i=1}^{n} x_{it} + \frac{\epsilon_t}{b}, \quad \epsilon_t \sim N(0,\sigma^2), \tag{4.1}$$

where t indexes the time period (month) and γ and $\lambda \equiv \frac{\rho\sigma^2}{b}$ are the parameters of interest. The NLS regression results are summarized in Table 4.2.

As can be seen from Table 4.2, the estimate for the observability parameter, $\hat{\gamma}$, is equal to 0.83 and is highly significant. We view this result as a first piece of evidence that strategic considerations play an important role in explaining the hedge ratios observed in the data. As said above, this can be interpreted as if firms attached approximately 80 percent probability to the event that their forward positions are

inverse hedge ratio for a given number of wholesale firms, n the number of wholesalers and u_n the usual error term. The estimates become $\hat{\alpha} = 1.36$ and $\hat{\beta} = -0.01$, with standard errors being equal to 0.06 and 0.006, respectively.

Parameter	Estimate	Standard Error
λ	11.98	26.61
γ	0.83*	0.03
$R^2 = 0.70$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent level

Table 4.2: NLS regression results

correctly forecasted by the rival firms upon observing the forward price. Seen from the perspective that most transactions at the TTF occur OTC, we find the result that the forward market is quite transparent interesting. It actually means that the market by itself is able to activate the role of forward sales as a commitment device.

The estimate for the risk aversion parameter, $\hat{\lambda}$, turns out not to be significant. This suggests that there is not clear evidence that risk-hedging is a key factor explaining observed hedge ratios in the Dutch natural gas market.[24]

The previous regression assumes demand volatility is constant over the sample period. If demand has become more (or less) volatile as time has elapsed, not controlling properly for such variation may lead to some form of omitted variable bias. Of course, changes in σ^2 are controlled for by changes in the forward sales. However, since σ^2 affects (4.1) directly, this control may be insufficient.

To explore this issue, we first construct a measure of demand volatility using spot market prices and use it to increase the variation in the data. Using Equation (3.10), and rearranging, we can write the equilibrium spot price as follows:

$$p_t = a_t - b \sum_i \Gamma_{it} x_{it} + \frac{1}{(n_t + 1)} \epsilon_t.$$

From this expression we can compute a measure of demand volatility:

$$\sigma_t^2 = (n_t + 1)^2 \sigma_{p_t}^2.$$

To determine the monthly volatility of demand shocks, we thus need some measure for price variability. For this, we first proxy daily spot prices by computing a weighted price index for day-ahead contracts. Then, monthly demand volatility, σ_t^2, is obtained by calculating the variance of the spot prices within a given month and multiplying

[24]We have also estimated Equation (4.1) for the case where n equals the number of all active wholesalers. We obtain similar results. The estimate for γ is equal to 0.76 and is significant at the 1 percent level, while λ, in this case becoming nearly zero, is again non-significant.

this measure by $(n_t + 1)^2$.[25]

Figure 4.4 plots (the natural logarithm of) our estimate for the monthly demand volatility. The graph shows that in some months the (estimate for the) demand variability is much higher than in other months and that demand has become more volatile over the sample period. This should explain part of the observed decrease in the inverse hedge ratios and, as a result, we would expect to obtain a lower estimate of the transparency parameter γ. The new estimates of equation (4.1) are in Table 4.3. In fact, the new estimate of the transparency parameter γ is somewhat lower and continues to be highly significant. Again we do not obtain significant evidence that risk is an important issue in this market.

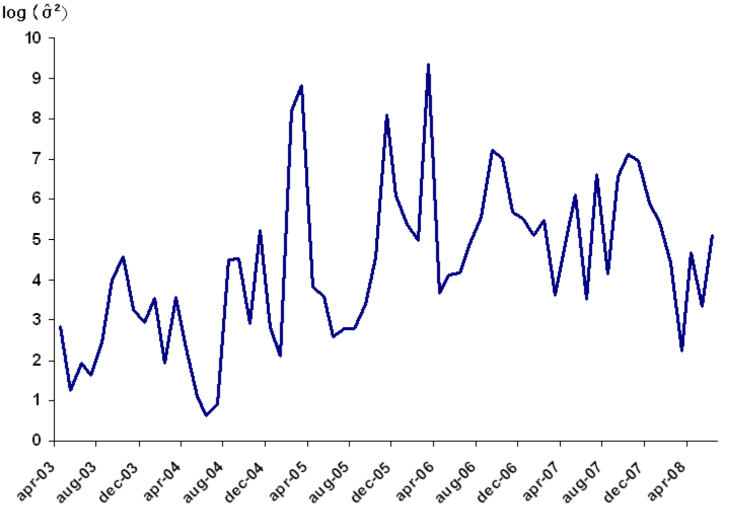

Figure 4.4: measure of demand uncertainty

It is conceivable that forward market transparency has increased over time. First, one can imagine that market participants' ability to interpret price signals has improved as time has elapsed. Second, it is also reasonable to believe that the quality and the quantity of the price indices available in the market has increased over time. Price information is now provided by information agencies such as ICIS Heren and Argus Media Ltd.,[26] brokers' associations such as LEBA[27] as well as the centralized

[25]Notice that using *ex post* price variation as a proxy for demand uncertainty relies on the assumption that firms have *ex ante* perfect foresight about the volatility of future (spot) prices. Campa and Goldberg (1993) use this approach to study the effect of exchange rate volatility on entry of foreign firms in the U.S. market during the 1980s.

[26]www.argusmedia.com

[27]London Energy Brokers' Association (www.leba.org.uk)

Parameter	Estimate	Standard Error
ρ/b	9189.1	$2.37 \cdot 10^7$
γ	0.70^*	0.02
$R^2 = 0.70$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent level

Table 4.3: NLS regression with demand volatility measure

marketplace ENDEX. Finally, the share of trades conducted (or cleared) at the gas exchange (vis-à-vis OTC) has increased over time and, since the exchange may be considered a more transparent marketplace than the OTC market, this adds to the supposition that the forward market as a whole has become more transparent. If this conjecture is borne by the data, we should observe an increase in the observability parameter γ over time.

To test this learning hypothesis, we introduce year dummies into the empirical model in (4.1). We continue to use the proxy for changes in demand volatility. As can be seen from Table 4.4, the new estimates show a positive trend in the observability parameter. When testing for differences between the year dummies, we find that the estimate for γ in 2004 is significantly lower than the estimates for γ in 2007 and 2008 at the 10 percent level. The results suggest that wholesalers' ability to infer deviations from equilibrium play has indeed increased over time, although this effect is not very strong.

Parameter	Estimate	Standard Error
ρ/b	9967.8	$1.65 \cdot 10^7$
γ_{2003}	0.81	0.68
γ_{2004}	0.30	0.30
γ_{2005}	0.67^*	0.09
γ_{2006}	0.66^*	0.05
γ_{2007}	0.71^*	0.04
γ_{2008}	0.71^*	0.03
$R^2 = 0.72$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent level

Table 4.4: NLS regression with demand volatility measure and year dummies.

We have searched for explanations for the result that there is no evidence that risk-hedging is an important factor to explain the observed inverse hedge ratios. One possible explanation is that being the strategic effect present and relatively strong, the incentives to hedge become rather weak. In fact, when γ is close to one, and for the firm numbers in our data (from 4 to 14 players), the share of the hedged quantity in total sales is already relatively large so the residual demand of a firm is quite low. This makes it rather difficult to precisely estimate the risk aversion parameter. To substantiate this observation, we plot the fit of the estimated model (with and without a proxy for σ^2), along with those which would prevail if the wholesalers were risk-neutral ($\lambda = 0.01$) or very risk averse ($\lambda = 100,000$).[28] The graph illustrates that the inverse hedge ratios predicted by the different levels of risk aversion are somewhat similar; as a result, one would need a very rich data set to precisely estimate the risk aversion parameter.

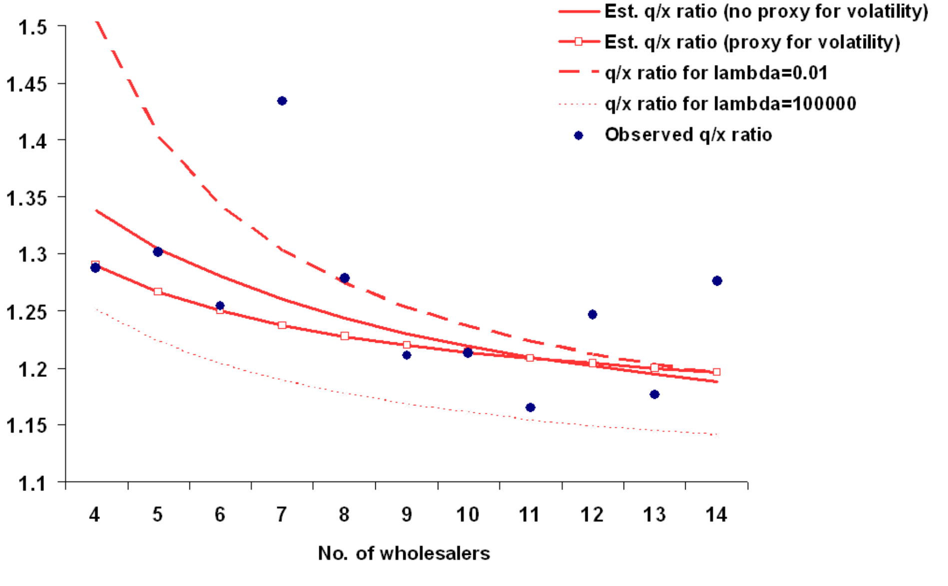

Figure 4.5: Fit of the model

Finally, we note that most TTF-trade is on high-calorific gas, for which demand is mainly industrial and for exporting purposes and therefore less subject to unpredictable weather shocks (see NMa/DTe, 2007). The other type of gas sold at the TTF is low-calorific gas. Demand for this type of gas is weather-driven to a larger

[28] To plot the fit of the regression with a proxy for demand volatility included, we take the sample mean of σ^2 and multiply this measure by the estimated ρ/b to get an estimate for λ.

extent because this type of gas is meant for household usage; however, due to limited conversion capacity, most of the low-calorific gas delivered in the Netherlands does not pass the TTF.

4.5 Discussion and further results

4.5.1 Uncertain spot market

In the previous chapter, we also studied the case in which firms do not observe price shocks before the spot market opens. We now take this variation to the data in order to see whether the estimation results for the basic model are robust to changes in the assumption on when the price shock becomes known. Applying the inverse hedge ratio obtained in the previous chapter (see Proposition 3.2), we start by fitting the relation

$$\frac{q_t}{x_t} = \frac{\gamma(n_t - 1) + (n_t + 1 + \frac{\rho\sigma^2}{b})(1 + 3\frac{\rho\sigma^2}{b} + \left(\frac{\rho\sigma^2}{b}\right)^2)}{(2 + \frac{\rho\sigma^2}{b})(\gamma(n_t - 1) + \frac{\rho\sigma^2}{b}(n_t + 1 + \frac{\rho\sigma^2}{b}))} + \varepsilon_t, \tag{4.2}$$

where ε_t is an error term. The NLS regression results are given in Table 4.5. The results are similar in that the estimate for the observability parameter is relatively high and highly significant. The estimate for the risk aversion parameter is again non-significant. The relatively low R^2 indicates that this model does less well in explaining the observed variation in inverse hedge ratios than the model estimated in Section 4.4.

Parameter	Estimate	Standard Error
λ	0.64	0.54
γ	0.72*	0.12
$R^2 = 0.12$		

Notes: n equal to wholesalers 80% of market

* Significant at the 1 percent level

Table 4.5: NLS regression results; no proxy for σ^2

To control for variation in demand volatility, as before, we add the appropriate proxy. In this case, using the equilibrium equations we observe that $\sigma_t^2 = \sigma_{p_t}^2$, so we just take the within-month variation in spot prices to proxy for the degree of demand uncertainty. The new estimates of Equation (4.2) are given in Table 4.6. Again, controlling for month-to-month changes in demand volatility does not seriously affect the regression results; the estimate for γ is still highly significant, while the estimate for λ seems not to be able to explain any variation in the observed inverse hedge ratios.

Parameter	Estimate	Standard Error
ρ/b	0.004	0.25
γ	0.85*	0.06
$R^2 = 0.07$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent level

Table 4.6: NLS regression with demand volatility measure

Finally, we look at the effects of including year dummies. The results are given in Table 4.7. We see that the learning effect becomes less prominent than in the model we estimate in the previous section.

Parameter	Estimate	Standard Error
ρ/b	0.002	0.59
γ_{2003}	0.98*	0.12
γ_{2004}	0.77*	0.20
γ_{2005}	0.87*	0.11
γ_{2006}	0.86*	0.10
γ_{2007}	0.84*	0.10
γ_{2008}	0.86*	0.10
$R^2 = 0.28$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent level

Table 4.7: NLS regression with demand volatility measure and year dummies.

In sum, we conclude that our results in the main body of this chapter are robust to this change in the modeling of the spot market. Irrespective of whether firms observe the demand shocks before they supply gas in the spot market or not, we find that strategic considerations are important at explaining the observed hedge ratios in the industry. By contrast, risk-hedging appears not to have a large explanatory power. Comparing the fit of the two models to the data, we note that the model where spot strategies can be tuned to accommodate the demand shocks has a much higher explanatory power.

In Figure 4.6 we show the fit of the two models to the data, where we have used the estimates reported in Tables 4.3 and 4.6 to construct the fitted curves. Both models suggest that the forward market is rather transparent, as the two estimated curves predict a fall in the ratio of interest when more firms become active at the TTF. However, the model that does not allow firms to condition their spot strategies on the realized demand shock predicts a higher impact of firm entry on the inverse hedge ratio. This clearly gives a less good fit of the data, as can be concluded from comparing the R^2 of both regressions.

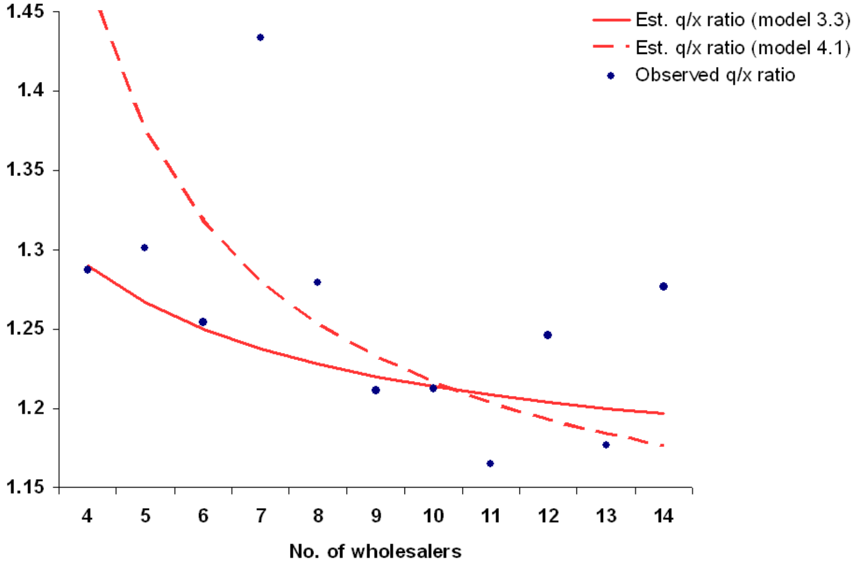

Figure 4.6: Fit of the different models

4.5.2 Endogeneity of the number of wholesalers

In our main model we have assumed demand is linear and this has implied that the relation to be estimated, Equation (3.15), does not depend directly on the demand intercept parameter and the marginal cost of the firms. As a result, data on demand and costs are not essential to estimate Equation (4.1) because changes in these variables are captured by changes in the forward sales. A related implication is that the estimates reported in Tables 4.2, 4.3 and 4.4 assume that the number of wholesalers is exogenous.

If, instead, we had used other demand specifications, the demand and cost parameters would probably have entered directly in the equilibrium condition we want to estimate. Omitting these variables, together with the fact that market profitability – and therefore the number of active wholesalers – at the TTF depends on market characteristics such as demand strength, the cost of supplying gas and the cost of entering the hub, raises the issue that the number of active wholesalers is not exogenous from an econometrics point of view. To address this potential endogeneity issue, we propose to use a free-entry condition that we estimate together with Equation (4.1).

We assume that gas wholesalers enter the TTF till the last firm that enters makes zero profit in expectation.[29] By substituting the equilibrium forward sales, given by Equation (3.10), into the expression for profits we obtain the following zero-profit condition:

$$(a-c)^2\Omega(b,\gamma,\rho,\sigma^2,n)/b - F + \nu = 0, \quad \nu \sim N(0,\sigma_\nu^2), \tag{4.3}$$

where F denotes a firm's cost of entry, $\Omega = \omega_1\omega_2$, with

$$\begin{aligned}
\omega_1 &= \frac{(n+1-\gamma(n-1))((n+1)^2+2\lambda)}{(n+1)^2}, \\
\omega_2 &= \frac{(n+1)^2(n+1+\gamma(n-1))+2(3(n+1)-\gamma(n-1))\lambda}{((n+1)^2(n+1-\gamma(n-1))+2\gamma n(n^2-1)+2(n(3-\gamma)+1+\gamma)\lambda)^2}
\end{aligned}$$

and the term ν is a random shock normally distributed with mean equal to zero and standard deviation given by σ_ν.

To add the information provided by the free entry condition (4.3) we need additional data. As a proxy for the demand intercept parameter a, we take monthly average prices of electricity spot contracts traded at the Dutch spot electricity exchange APX. In particular, we assume $a_t = a_0 + a_1 e_t$ where a_0, a_1 are free parameters and e_t is the spot price of electricity in period t.[30] On the cost side, we consider the oil price as being informative for the marginal production cost of a gas wholesaler. The rationale behind this is that prices in long-term contracts between gas producers and wholesalers are often indexed by the oil price. We therefore proxy the monthly

[29] While in our theoretical framework firms maximize expected utility once they have entered the market, we assume that firms base their entry decision on expected profits. A practical reason for doing this is that in case we let firm entry incentives be based on (expected) utility, the entry condition, which we are going to exploit in the estimation, becomes very cumbersome to deal with. One theoretical validation for the dissimilarity between firms' pre-entry and post-entry objectives is that market entry is decided upon by firm owners, who are typically assumed to be risk neutral, while daily control is delegated to firm managers, who are often considered as being risk-averse.

[30] As mentioned above, a great deal of the gas traded in the TTF is high-calorific gas whose main use is in industrial applications such as the production of ammoniac as well as in the production of electricity.

marginal cost by $c_t = c_0 + c_1 o_t$, where c_0, c_1 are free cost parameters and o_t is the monthly world oil price.

It is difficult to obtain information on entry costs. Wholesalers operating in the TTF have to pay a fixed fee of 1,263 Euros to register at the TTF for a single gas month. In addition, if these wholesale firms also want to participate in the centralized exchanges, they have to pay an extra fixed fee of 2083 Euros per month.[31]

We thus estimate the following system of equations:

$$\begin{pmatrix} y_t \\ 0 \end{pmatrix} = \begin{pmatrix} g(n_t, \sum_{i=1}^{n} x_{it}, \gamma, \sigma_t^2, \rho, b) \\ \xi r(a_t, c_t, F, n_t, \gamma, \sigma_t^2, \rho, b) \end{pmatrix} + \begin{pmatrix} \epsilon_t \\ \xi \nu_t \end{pmatrix}, \quad \begin{pmatrix} \epsilon_t \\ \xi \nu_t \end{pmatrix} \sim \left(0, \begin{pmatrix} \sigma_{\epsilon_t}^2 & 0 \\ 0 & \sigma_\nu^2 \end{pmatrix}\right), \tag{4.4}$$

where

$$\begin{aligned} y_t &\equiv \frac{n_t + 1}{n_t} \sum_{i=1}^{n} s_{it} \\ g\left(n_t, \sum_{i=1}^{n} x_{it}, \gamma, \sigma_t^2, \rho, b\right) &\equiv \frac{n_t + 1}{n_t} \left(\Gamma(n_t, \gamma, \sigma_t^2, \rho, b) - 1\right) \sum_{i=1}^{n} x_{it} \\ r(a_t, c_t, F_t, n_t, \gamma, \sigma_t^2, \rho, b) &\equiv (d + a_1 e_t - \beta_1 c_t)^2 \Omega(n_t, \gamma, \sigma_t^2, \rho, b) - F_t \end{aligned}$$

and $d = a_0 - c_0$ and ξ is a weighting parameter that is attached to the restrictions. Since the degree of informativeness of the zero-profit conditions depends on the variability of these restrictions, we set ξ equal to the ratio of the standard deviations of the two error terms in (4.4), $\xi = \sigma_{\epsilon_t}/\sigma_\nu$.[32] The new regression results are summarized in Table 4.8.

Parameter	Estimate	Standard Error
ρ/b	$3.5 \cdot 10^5$	$5.26 \cdot 10^8$
γ	0.70^*	0.02
$R^2 = 0.68$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent significance level

Table 4.8: NLS regression results with endogenous n

The estimates of the key parameters do not change much if we include the

[31] Next to the fixed fee, participants pay a variable tariff for each MWh traded in the TTF. These variable fees are picked up by the constant c_0 in our estimation.

[32] We conduct a feasible weighted NLS regression (see Greene, 1993, p. 209-211). The estimate of the weight ξ is given by $\hat{\xi} = \sqrt{\frac{\hat{\epsilon}'\hat{\epsilon}}{\hat{\nu}'\hat{\nu}}}$, which is the square root of the ratio of the sums of squared residuals.

stochastic zero-profit conditions in the regressions. The strategic effect is again highly significant, while the risk-hedging motive is still non-significant.

4.5.3 Imperfect observability by financial traders

In the analysis so far we have assumed that financial traders are informed about the wholesalers' forward positions at all times. The implication of this assumption is that a strong version of arbitrage (off and on the equilibrium path) between forward and spot markets holds. In this Section we explore the importance of this assumption. If, instead, speculators do not observe the wholesalers' forward positions at all, they do not react to out of equilibrium deviations. As a result, the forward price is rigid and does not change off the equilibrium path. Of course in equilibrium traders' beliefs are correct, so that $f = E(p)$ still holds true.

To explore the role of this assumption, we propose to consider the case in which financial traders observe wholesalers' forward positions imperfectly. We model this idea by introducing a new Bernoulli random variable, denoted I_s, with parameter μ. If $I_s = 1$ deviations in the forward market become observed by the financial traders; this occurs with probability μ. If $I_s = 0$, forward positions remain opaque and the forward and the spot price need not coincide off the equilibrium path. The parameter μ can then be interpreted as the extent to which the forward transactions are observed by the financial traders/speculators.

In this case, the average hedge ratio is

$$\Gamma_i = \frac{b(n+1)^2((n-1)(2-\mu)\gamma + (1+n)\mu) - 2(2+\mu(1+\gamma) + (2+\mu(1-\gamma))n)\rho_i\sigma^2}{2(n+1)(b(n^2-1)\gamma + 2\rho_i\sigma^2)}. \tag{4.5}$$

Note that

$$\frac{\partial \Gamma_i}{\partial \mu} = \frac{(1+\gamma+n(1-\gamma))(b(n+1)^2 + 2\rho_i\sigma^2)}{2(n+1)(b(n^2-1)\gamma) + 2\rho_i\sigma^2} > 0.$$

Therefore, as the probability that traders observe deviations goes up, a smaller fraction of a firm i's output is hedged. The intuition or this result is simple: everything else equal, the negative price effect brought about by a firm's forward sales (referred to above) strengthens as the forward market becomes less opaque for the speculators (spot and forward price falls only if this deviation is anticipated by the traders).

We now estimate this extension where the traders observe forward positions with probability μ. This amounts to fitting Equation (4.1) modified by the fact that the average hedge ratio is now given by (4.5). We obtain an estimate of speculators' observability parameter μ. The new estimates are in Table 4.9.

Parameter	Estimate	Standard Error
λ	0.00	108.43
γ	0.63 *	0.08
μ	0.47	57.24
$R^2 = 0.71$		

Notes: n equal to wholesalers 80% of market
* Significant at the 1 percent significance level

Table 4.9: NLS regression results with imperfect financial traders

The new results show a somewhat weaker strategic effect, though, in line with the previous results, it is still highly significant. We continue not obtaining conclusive evidence that the risk-hedging effect is relevant in our market. Finally, the observability parameter of the financial traders equals 0.47, though it is not estimated with much precision.[33]

Lastly, we estimate the model with imperfect trader observability by including year dummies for γ. The results are displayed in Table 4.10. We again observe an increase in the year dummies, which suggests that the strategic motive has gained more importance over the years. However, since none of the estimates is significant we do not want to draw any strong conclusion from these results.

Parameter	Estimate	Standard Error
λ	30.26	214.79
μ	0.38	0.87
γ_{2003}	0.32	1.11
γ_{2004}	0.00	1.19
γ_{2005}	0.37	0.51
γ_{2006}	0.40	0.45
γ_{2007}	0.48	0.47
γ_{2008}	0.48	0.47
$R^2 = 0.73$		

Notes: n equal to wholesalers 80% of market

Table 4.10: NLS regression results with imperfect trader observability and year dummies

[33]When instead of using 80% of the wholesalers we use all of them, we obtain an estimate of γ equal to 0.76, with a standard error of 0.05, an estimate of λ equal to 0.00, with a standard error of 712.21, and an estimate of μ equal to 1.00, with a standard error of 521.73.

4.6 Concluding remarks

Using data from the Dutch wholesale market for natural gas where we observe the number of producers and wholesalers, forward and spot sales, and churn rates, we find evidence that strategic reasons play an important role at explaining the observed firms' hedge ratios. By contrast, the data do not support the idea that risk-hedging motives are an important aspect behind the observed firms' hedge ratios. Seen under the perspective that most of the forward transactions in the Dutch natural gas market occur OTC we think this is an important result. We also document a (moderate) learning effect, which is probably related to the development of the market.

4.A Appendix

All contracts traded in the TTF call for physical delivery of natural gas at the GTS transmission grid. Concerning forward transactions, the most prominent types of contracts are the ones that are also eligible at ENDEX:[34]

- Single-month contracts; these contracts can be traded from three months ahead till the expiration date, which is, with the exception of holidays, the penultimate working day of the month that precedes the month of delivery. The monthly contract then moves into delivery at the GTS transmission grid.

- Single-quarter contracts (quarters being defined as January-March, April-June, July-September and October-December); trade in these contracts starts four quarters ahead and continues till the moment the contract expires. For this product, the day of expiration is the last but two working days of the last quarter before physical supply takes place. After expiration, the quarterly contract converts into three monthly contracts.

- Single-season contracts (seasons being defined as April-September and October-March); these contracts can change hands from four seasons ahead till the day of expiration, which is the last but two working days of the season preceding the delivery period. When the seasonal contract expires, it falls into three monthly contracts and one quarterly contract.

- Single-calendar-year contracts (calendar year being defined as January-December); these contracts can be traded from three calendar years ahead till the moment of expiration, which is the last but two working days of the last year before the gas is delivered. After the contract expires, it cascades into three monthly contracts and three quarterly contracts.

The minimum volume that can be specified in quarterly, seasonal and calendar contracts is 10 MWh/h; for monthly contracts, this minimum volume equals 30 MWh/h.

Next to forward contracts, participants also trade spot contracts at TTF. Two types of spot market contracts can be distinguished:

[34]There exist also some contracts that can be traded OTC but not in the centralized exchange ENDEX. Among them are the *Balance-of-Month* (BOM) and *Working-Days-Next-Week* (WDNW) contracts. These kind of forward products constitute only a tiny share of the total number of the transactions in the TTF.

- Day-ahead contracts; the trading market for these contracts opens two working days before physical supply takes place and closes two hours prior to the start of delivery.
- Within-day contracts; these contracts can be traded from 26 hours prior to delivery till two hours before the gas is physically supplied.

Chapter 5

Oligopolistic competition, OTC markets and centralized exchanges

.

5.1 Introduction

As explained in the previous chapters, the gradual unbundling of vertically integrated monopolies allows policy makers to introduce markets for commodities. This creates room for new firms to become active at the wholesale level, as long as they find sufficient opportunities to buy from upstream producers and, at the same time, to reach downstream buyers.[1] In order to foster competition between energy wholesalers, policy makers have facilitated the introduction of spot markets where buyers and sellers can transact anonymously and at high speed. It is intended that spot-based trade will eventually take over the dominant position of one-to-one negotiations, which used to be the standard of trade in the pre-liberalization period.[2]

[1] The European Commission has raised the concern that there are still significant barriers to enter European energy wholesale markets. Among the most important reasons for the existence of entry barriers are inadequate unbundling of network operators, insufficient opportunities for cross-border trade and a lack of transparency in various market operations (see EC, 2007).

[2] In natural gas markets, trade in the pre-liberalization period was dominated by take-or-pay agreements between producers and the integrated monopolies at the upstream level, and between the integrated companies and retailers or industrial consumers at the wholesale level. Take-or-pay

Organized energy spot markets usually take the form of business-to-business (B2B) exchanges. These B2B exchanges operate electronic platforms which, being accessible via direct connections, telecom hubs or the Internet, give buyers and sellers the opportunity to meet each other in the virtual marketplace.[3] In order to transact at the platform, traders typically have to pay a fee to become a member of the exchange. Well-functioning exchanges bring together a large number of traders, thereby facilitating the searching and matching process of buyers and sellers. Other intermediation services delivered by centralized exchanges are for instance clearing, providing liquidity and ensuring immediacy (Spulber, 1996).[4] In addition to the creation of B2B spot exchanges, we have witnessed the emergence of trading platforms where energy derivatives like futures and options can be transacted. This gives market players the opportunity to hedge price risks they bear from trading in the spot market (see e.g. Bessembinder and Lemmon, 2006; Wu and Kleindorfer, 2005). Trade at spot and derivatives exchanges is often characterized by the system of double auction, where buyers and sellers can place offers and deals are executed as long as a buyer's bid price is higher than the price offer of the seller (Cripps and Swinkels, 2006).

There exist various reasons why, from a societal point of view, spot markets are considered to be more desirable than bilateral negotiations in over-the-counter (OTC) markets. First, prices in bilateral contracts are typically fixed or indexed to the price of another commodity, which implies that contract prices do not strongly react to changes in supply and demand. This reduces market transparency and the information content of prices, leading to inefficiencies like over- or underproduction and socially undesirable investment decisions. By contrast, traders on a liquid spot market are ready to arbitrage away any market imbalances thereby bringing trade

contracts require the buyer to pay for a pre-specified amount of gas, even in case the gas is not taken. While the purchaser bears the quantity risk, the seller is exposed to price risk since the contract price is usually indexed to the oil price (Masten and Crocker, 1985). One type of long-term electricity contract is the long-term power purchase agreement (PPA). The purchaser of a PPA has the obligation to buy from a power generator during the entire contract period, which in general is between 5 and 25 years.

[3] ICE (active in the U.S., Canada and Europe), APX and EPEX (both only active in Europe) are examples of electronic spot exchanges where members can trade short-term contracts for various energy commodities.

[4] Many exchanges provide clearing and settlement services to reduce a trader's risk of nondelivery or nonpayment in case of default by a counterparty. Immediacy services, provided by exchange brokers who trade for their own account, give traders the opportunity to trade immediately. Liquidity, meaning that exchanges are characterized by a high level of trading activity, reduces the risk of not finding a trading partner on short notice.

more in line with changes in supply and demand.[5] Secondly, long-term relationships may weaken competitive pressures in the wholesale market as they have the potential to deter entry on the seller's side as well as on the buyer's side. In its 2007 Energy Sector Inquiry, the European Commission argues that the predominance of long-term contracts in European gas and (to a lesser extent) electricity industries hinders the development of sound competition at both the wholesale and retail level (EC, 2007).

Despite the efforts undertaken to shift trade from bilateral negotiations to more centralized marketplaces, buyers and sellers still rely to a large extent on the OTC market to transact energy contracts.[6] Admittedly, in many countries the liberalization process is still not finalized and centralized marketplaces have not fully developed yet. However, even in countries where there exist mature exchanges, like the U.S. and the U.K., a significant share of trade is still conducted over-the-counter.[7] The question thus arises why OTC markets and centralized exchanges exist side by side in energy industries.

A first explanation for the coexistence of the above-mentioned trading institutions is that exchange-based contracts are not always identical to contracts transacted over-the-counter. Typically, exchanges only facilitate trade in standardized contracts that have a high order flow. A hedging portfolio that only consists of exchange derivatives may therefore not be sufficient to cover all types of risk. This particularly holds when buyers and sellers face risk that has an idiosyncratic character (Duffie, Gârleanu, Pedersen, 2007; Duffie, Li and Lubke, 2010). Market parties then have an incentive to become active in the decentralized OTC market, where tailor-made products are traded that enable agents to hedge trader-specific risk exposure. Moreover, even when market players are risk-neutral they may benefit from the high degree of flexibility bilateral contracts usually provide. For instance, data on the Dutch wholesale market for natural gas tell us that none of the industrial consumers (like electricity generators or ammonia producers) is active at the Dutch

[5]Moreover, as mentioned before, the typical spot market for gas as well as for electricity is governed by an auction-like trading mechanism. Auctions are typically efficient mechanisms for the exchange of goods, as they enhance competition among bidders and also make it possible to exchange goods quickly.

[6]In 2008, about 10 percent of the high-calorific gas traded in the Netherlands passed the centralized hub Title Transfer Facility (TTF) (see Chapter 4 of this thesis). Trade at the European electricity spot exchanges EEX (Germany), APX (The Netherlands) and Powernext (France) accounted for respectively 17, 13 and 4 percent of total national consumption in 2008 (see EC, 2007).

[7]For instance, total 2007 trade conducted at the National Balancing Point (NBP), which is the natural gas hub in the U.K., accounted for approximately 67 percent of yearly U.K. consumption. However, a subtantial share of the NBP transactions are done over-the-counter.

gas hub TTF. One of the main reasons for this phenomenon is that natural gas is just one of the several possible inputs that can be used in the production of electricity or ammonia. Therefore, the usage of gas as an input largely depends on the gas price relative to prices of other fuels, like coal. Demand for gas as an input is thus rather volatile and makes it beneficial for industrial consumers to sign flexible contracts with gas suppliers.[8]

Clearly, there are good reasons to believe that product differentiation plays an important role in explaining the coexistence of one-to-one negotiations and trade at centralized exchanges. Nevertheless, given that it becomes increasingly customary that OTC markets provide "exchange-like" services like clearing, it seems that at least part of the OTC-traded contracts are very similar to exchange products.[9] Given the various costs associated with executing deals in decentralized marketplaces and exchanges, it is not clear at first sight why both market institutions are used to transact the very same types of products.

This chapter addresses the question whether OTC markets and centralized marketplaces can exist side by side even if all products traded in the market are identical. We model the competition between oligopolistic firms offering a homogeneous good to consumers who differ in their willingness to pay.[10] There are two marketplaces where the good can be traded: a decentralized OTC market, where buyers and sellers are randomly matched and bargain over the price; and a centralized exchange operating a (electronic) platform, where firms engage in posted price competition and all buyers can obtain the good against the lowest price posted. Though in practice most exchange-based trade is conducted using the double auction mechanism, for reasons of tractability we assume here that only firms can post a price offer in the platform.[11]

[8]In the natural gas industry, these flexibility services are provided by the take-or-pay contracts. These contracts, though they require the buyer to pay for a pre-specified gas volume, usually contain a range of daily and yearly flexibility services (Asche *et al.*, 2002).

[9]This trend has been recognized by industry participants. Phil Atkinson, Managing Director of the energy broker ICAP Energy, claims that "All OTC brokers offer exchange look-a-like products on their electronic platforms" (APXGroup, 2008).

[10]In the context of energy wholesale markets, consumers could not only be seen as final users but also as retailers who in turn sell to their costumers. Then, a retailer's willingness to pay relates to her profitability from reselling the good that is bought at the wholesale level.

[11]For the sake of exposition we model the mode of competition at the different market institutions as follows. For the decentralized marketplace, we assume that a consumer is randomly matched to a seller and can never search for an attractive offer from another firm. By contrast, suppliers in the centralized marketplace have an incentive to behave competitively because the lowest-priced firm attracts all consumers who join the platform. We thus assume here that 'stock outs' never occur. In practice, the difference between the competitive forces in OTC markets and exchanges is not as extreme as modelled here. Buyers can search for alternative offers in the decentralized market

In the decentralized market, buyers share the surplus from trade with sellers which implies that a high-type consumer (i.e. a consumer with a high willingness to pay) pays a higher price than a low-type buyer. Conversely, the price a consumer pays in the exchange does not depend on her willingness to pay. This implies that sellers can price discriminate across channels as well as in the OTC market. In order to utilize the platform, buyers and sellers however have to pay a participation fee to the exchange. These differences in the cost of transacting at the two trading institutions leads to buyer segmentation: consumers with a high willingness to pay join the centralized marketplace, while low types obtain the good through bargaining in the OTC market.[12]

This segmentation on the buyer's side may lead one to think that sellers have an incentive to be active on both marketplaces. Since a firms's payoff from negotiating is always positive, all sellers engage in bargaining in the OTC market. By contrast, given that the platform owner may charge sellers a participation fee, it is not clear at all that a firm finds it always profitable to make use of the exchange's services. We show that a firm's decision whether or not to enter the platform depends on various aspects, like the participation fees set by the exchange, the (expected) share of buyers that visit the platform and the relative bargaining power of sellers in the OTC market. A seller's entry propensity relates to the degree of liquidity on the B2B marketplace, as it determines how likely buyers find a counterparty at this trading institution. Moreover, a seller has to take into account how its actions in the platform affect its profit in the decentralized market. For instance, a firm could post a very low price so as to outbid rival firms and lure a large share of buyers to the trading platform. Such a strategy leads to a profit in the platform, but has a negative effect on the firm's payoff in the OTC market since most consumers buy in the centralized marketplace against the low price set by the firm.

Furthermore, we look at the behavior of a monopolistic exchange that sets participation fees in order to maximize (expected) profit. We focus on the matching role

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and a firm that does not set the lowest price at the platform usually still sells to some buyers, especially when sellers do not hold large inventories. A more elaborate model would therefore have intermediate forms of competition in both institutions. However, as long as in real-world energy industries electronic platforms are more competitive environments than OTC markets our model is adequate to study behavior in markets where both trading institutions coexist.

[12]We assume that there are no speculative traders who arbitrage away price differences between the platform and the decentralized market. Although we have recently witnessed the entry of financial players like Morgan Stanley and Citigroup in energy exchanges, prices across the different trading institutions seem not to converge fully. In the natural gas industry, oil-linked contract prices are in general higher but less volatile than hub prices (EC, 2007).

of the exchange, leaving aside other intermediation activities like clearing and providing immediacy. When deciding on the fees, the exchange has to take into account that the buyer's and seller's demand for using the trading platform are interdependent.[13] That is, an increase in the seller fee not only changes the exchange's payoff flowing from the seller's side, but it also (negatively) affects the revenues obtained from consumers. This is because raising the member fee for sellers leads to a fall in the probability of firm entry and therefore reduces competitive pressures on the platform. This makes the centralized exchange a less attractive marketplace for buyers to enter. Likewise, if the platform owner increases the buyer fee in order to get more revenues from consumers, at the same time it loses revenues on the seller's side. The reason for this is that a fall in the fraction of buyers who join the exchange lowers the likelihood that firms enter.

Finally, we show that the profitability of providing intermediation services crucially depends on the institutional characteristics of the centralized marketplace. In our basic model, we assume that a firm that enters the centralized marketplace chooses which price to post before it gets to know the entry decision of rival firms. In that case, the exchange maximizes profits by letting sellers in for free while charging buyers a strictly positive fee. A zero seller fee does not generate any revenues from the seller's side, but ensures that all firms enter with probability one, driving down the exchange price to marginal cost. This makes platform participation attractive for a large share of buyers, who are willing to pay a relatively high fee to join the centralized exchange. Though the buyer fee is higher than the seller fee, consumers gain and firms lose from the provision of intermediation services. This is because the presence of the exchange makes the market more competitive.

In an extension to our basic model, we consider the situation in which firms that have entered pick a price only after observing whether any of their competitors has also decided to become active at the trading platform. This leads to marginal cost pricing in the centralized marketplace as long as two firms decide to enter, irrespective of the height of the seller fee. Firms therefore find it not very attractive to enter, since they realize that their decision to enter may lead to fierce competition at the platform. Moreover, strong competition in the centralized marketplace results in more consumers buying there, which has a negative impact on a firm's OTC profit. Compared to the basic setting, the equilibrium profit of the exchange is lower and moreover, the centralized marketplace is less liquid.

[13]Due to these interdependencies, centralized exchanges exhibit the characteristics of two-sided markets. Seminal papers that examine monopolistic platform intermediation in two-sided settings are Armstrong (2006) and Rochet and Tirole (2003).

The rest of the chapter is structured as follows. The next section presents a literature overview. In this overview, we not only discuss the most relevant work on competition between trading institutions, but we also explain how our framework differs from the existing work on this topic. Then, we describe the set-up of the basic model in Section 5.3. Section 5.4 analyzes the optimal trading strategies of buyers and sellers and the fee setting behavior of the exchange. In Section 5.5, we consider a variation to the basic model by assuming that firms that enter the centralized marketplace observe the entry decision of their competitors before posting their exchange price. Lastly, we discuss our main results and give some concluding remarks. Most of the figures in this chapter can be found in the Appendix.

5.2 Literature overview

This chapter studies competition between sellers in case trade takes place at two different trading institutions. Most of the literature in this area focuses on the optimal selling mechanism for suppliers in case only one institution can be chosen at a time. Wang (1993) studies whether it is profitable for a monopolistic seller to auction a product rather than to post a (non-negotiable) price. He shows that in markets where the valuation of buyers is more dispersed, an auction yields the highest payoff for the seller. Bester (1993) and Wang (1995) compare the profitability of posted-price selling with that of bargaining. In Bester (1993), oligopolistic producers sell to buyers who are imperfectly informed about the quality of the products being offered. Which pricing mechanism is chosen depends on how easy it is for consumers to switch between the different competitors. Wang (1995) examines how the haggling cost of bargaining, relative to the cost of posting a price, affects a monopolist's choice of selling method. If the relative cost of bargaining is not too high, the seller opts for selling its product through bilateral negotiations with buyers. Given that in many real-world markets buyers and sellers use more than one marketplace to execute deals, studying trading behavior at the different trading institutions in isolation may give an incomplete picture of markets in which more than one selling mechanism exists.

Most of the few papers studying the *coexistence* of two or more trading mechanisms focus on the role of a centralized market maker that matches trade between buyers and sellers who otherwise could only execute deals over-the-counter (see e.g. Gehrig, 1993; Rust and Hall, 2003; Neeman and Vulkan, 2010). Unlike the centralized exchange in our model, market makers match both sides of the market by buying and selling on their own account. By trading against the publicly announced bid and ask prices of the market maker, market participants can avoid the friction cost they would incur by transacting in the decentralized market.[14] The market maker's intermediation services are especially attractive for high-valuation buyers and low-cost sellers, which are the traders that bear relatively high friction costs in the OTC market. Since the market maker charges a positive spread between the bid and ask price in order to maximize profit, the low-valuation buyers and the high-cost sellers find it unprofitable to make use of the market maker's intermediation services and therefore search for a trading partner in the decentralized market. The market outcome is characterized by segmentation on both sides of the market.[15]

For an intermediary, one way to match market players is to trade for her own account. However, in many recently established energy exchanges the main intermediation activity is just the facilitation of the matching process between buyers and sellers, who then trade directly with each other. These so-called *matchmakers* give sellers and buyers the opportunity to meet each other without having to search for a counterparty nor to engage in costly bargaining.[16] Yavaş (1994) studies the role of a monopolistic matchmaker in a search market that is inefficient in two ways: agents do not always find a trading partner and the positive externality an agent's search intensity creates for the other side of the market (since it increases the probability of a match) is not internalized. The matchmaker alleviates these inefficiencies by matching agents. If traders are matched to a counterparty by making use of the matchmaker's services, they pay a portion of the surplus they obtain from trade as matching fee.[17] Like Yavaş, we look at an intermediary that brings together

[14] Gehrig considers an exogenously given probability that there is a mismatch in the decentralized market, which causes the friction cost. In Rust and Hall and Neeman and Vulkan, the cost of searching for prices in the decentralized market is modelled as a delay cost and stems from two sources: first, traders discount future payoffs and second, there is an exogenous probability that traders exit the market in the future without having been able to trade in case they do not accept the offer they receive in the current period.

[15] Neeman and Vulkan however come to a quite remarkable result: the centralized market causes an 'unraveling' effect in the search market, which results in that all trade is conducted at the centralized marketplace. This finding relies on the assumption that the centralized market is operated by a non-for-profit organization that charges a zero spread. Kugler, Neeman and Neeman (2006) provide laboratory evidence for some (but not full) unraveling of the decentralized market.

[16] A paper that endogenizes the choice of an intermediary to become a matchmaker or a marketmaker is Yavaş (1992). For the case where the agents' valuations are private information, it is shown that matchmaking yields higher profits than marketmaking when searching is costly for traders and the search market in itself is inefficient.

[17] Since the fee in the model of Yavaş is proportional to the gains from trade, high-valuation buyers and low-cost sellers pay a higher price for the matching service and therefore bypass the

market players without buying and selling on her own account. Our model differs from Yavaş' in that we consider oligopolistic competition at the seller's side, whereas Yavaş assumes perfect competition between sellers. Moreover, Yavaş allows traders to be active at only one trading institution at a time while we let firms themselves decide whether they become active on both marketplaces.

The research reported in this chapter comes closest to the work of Baye and Morgan (2001) on information gatekeepers (hereafter referred to as BM). They examine the role of a gatekeeper that acts as an information provider in a world where several local markets exist. Without the provision of the gatekeeper's services, consumers can only buy from their local shop. By operating a website where firms can advertise their prices, the gatekeeper gives consumers the opportunity to buy from the firm that advertises the lowest price, even if this firm is not the local shop. In the context of energy markets, the gatekeeper's website is analogous to a centralized exchange where firms compete fiercely to attract a large share of consumers, while the local market in BM can be seen as a decentralized marketplace where competitive pressures are less strong.

Our model however differs in two main aspects from the framework that is analyzed by BM. First, we assume that buyers differ in their willingness to pay while BM consider homogeneous consumers. Secondly, in our case the price each individual buyer pays in the decentralized market depends on his willingness to pay. In BM, by contrast, consumers are identical and cannot bargain over the price with the local monopolist, which implies that they all pay the same price in the decentralized market. Changing these two key elements leads to quite dramatic changes in the equilibrium outcome. In contrast to our buyer segmentation result, BM find that the gatekeeper sets buyer fees such that all consumers choose to subscribe to the gatekeeper's website. That also implies that in the BM equilibrium there is no decentralized trade.[18] Moreover, the gatekeeper in their model sets an advertising fee for sellers such that it does not lead to full producer participation.[19] In our model,

matchmaker. The remaining agents, who suffer less from rent extraction by the matchmaker, make use of the intermediation services. Clearly, the reason that Yavaş obtains a market segmentation result that mirrors our outcome and the results in the work on market makers is simply that he considers a different tariff structure.

[18]Setting a higher participation fee for consumers can never be profit-maximizing for a gatekeeper, since then no consumer would subscribe to the website and, as a result, producers would not have an incentive to make use of the gatekeeper's market for information.

[19]Firms advertise prices in the website with probability strictly less than one, so that there is price dispersion in the website and firms avoid driving the platform price to the competitive level. This enables the gatekeeper to extract part of the rents that producers obtain from participating in the platform.

all firms are active in the centralized marketplace as well as in the OTC market.

Galeotti and Moraga-González (2009), studying another variation to the BM model, consider a setting where oligopolistic firms sell differentiated products on a platform. They show that the platform's manager lures all buyers and sellers to the centralized marketplace and engages in full rent extraction on both sides of the market. In case it is possible to execute deals over-the-counter, the intermediary leaves some rent to the consumers so as to ensure that still all transactions are conducted on the platform. This result is driven by the assumption that all consumers are *ex ante* identical and therefore take similar decisions regarding platform participation.

5.3 The basic model

We consider an oligopolistic market where $n \geq 2$ symmetric firms produce a homogeneous good at constant marginal cost. Without loss of generality, we normalize the marginal cost of production to zero. On the buyer's side, there is a unit mass of consumers who differ in their willingness to pay. Let v_i denote buyer i's valuation for the product; v_i is uniformly distributed on the interval $[0, 1]$. Furthermore, we assume that each consumer buys at most one unit of the good.

There exist two trading institutions where both sides of the market can meet and transact with each other: a decentralized OTC market and a centralized platform. In the OTC market, buyers and sellers are randomly matched and once matched, they bargain over the price of the good. We assume that the price that prevails in an OTC deal is given by the generalized Nash bargaining solution, which depends on the seller's relative bargaining power $\alpha \in (0, 1)$. Given that a fraction α of the surplus from trade, which equals v_i, flows to the seller, higher-valuation buyers pay a higher price in the decentralized market than consumers with a lower willingness to pay.[20]

The platform is operated by a monopolistic exchange, which brings together buyers and sellers. Firms that join the platform engage in posted price competition. Since products are homogeneous, the firm that posts the lowest price serves all consumers who enter the centralized marketplace. Concerning the fee setting behavior of the intermediary, we consider several cases. We first study the optimal fee structure for the exchange when only one side of the market can be charged. Then, we look at the case where the platform owner is allowed to charge both buyers and sellers a

[20] To account for the fact that suppliers usually face more competition in the exchange than in the OTC market, we assume that buyers have such high search cost after being matched to a seller that it never pays to search for a better offer.

participation fee for making use of the the exchange's services. The buyer and seller fees are denoted by b and s, respectively.

Since engaging in bargaining involves no cost, all sellers will be active in the OTC market. When it comes to the decision whether to participate in the centralized marketplace, the set of possible pure strategies for firm j is given by $S_j = \{E, NE\}$. Here, E and NE represent the decisions to enter the platform or not to enter, respectively. Let β_j then be the probability that firm j chooses to join the centralized platform. Furthermore, a firm j that enters the platform chooses a price to be posted there. In general, let the price strategy of a firm j be given by a cumulative distribution function $F_j(p)$, with support on $[\underline{p}, \bar{p}]$ and density function $f_j(p)$. If the distribution function degenerates into a single mass point, the firm adopts a pure strategy; otherwise it plays a mixed strategy. Since we only consider symmetric equilibria, subscripts will be dropped from the firms' strategies in the remainder of the chapter.

The timing of the game is as follows. In the first period, the exchange sets participation fees for sellers and buyers. In the next period, suppliers decide whether to participate in the exchange and if so, the price they post there. In the last period, buyers, observing the prices posted in the platform (if any), decide whether to get access to the exchange by paying the fee and buy the product there or to bargain with a seller in the OTC market.[21]

5.4 Analysis

5.4.1 Consumer participation decisions

Applying backward induction, we first characterize the optimal shopping behavior for buyers. Since there is no cost involved in entering the negotiation process, all consumers who do not buy in the centralized marketplace go to the OTC market where they are randomly matched to a firm. Let p_b^i be the price a seller and a consumer of type v_i agree upon in the OTC market after being matched to each other. This price is the generalized Nash bargaining solution:

$$p_b^i = \text{argmax}_y y^{\alpha}(v_i - y)^{1-\alpha}.$$

[21] In contrast to BM and Galeotti and Moraga-González (2009), we assume that consumers decide where to buy after having observed the lowest price posted in the platform which avoids *ex post* consumer regret.

The bargaining price for buyer of type i thus equals

$$p_b^i = \alpha v_i. \tag{5.1}$$

Equation (5.1) shows us that high-valuation buyers pay a higher price in the OTC market than buyers who have a lower willingness to pay. To determine the fraction of consumers who enter the decentralized market, first note that the net utility consumer i derives from negotiating equals $(1-\alpha)v_i$. If consumer i buys in the exchange instead, her net utility equals $v_i - p_e - b$, where p_e is the minimum of all prices posted at the platform (if any) and b is the fee buyers have to pay in order to get access to the exchange. When no firm enters, trade cannot take place in the centralized marketplace and all consumers obtain the good through bargaining. Suppose first that at least one seller did enter the exchange's platform. Then, the consumer $\bar{v}$ who is indifferent between buying at the platform and obtaining the good through bargaining is given by

$$\bar{v} = \frac{p_e + b}{\alpha}. \tag{5.2}$$

All consumers with valuation $v_i \leq \bar{v}$ rely on bargaining to obtain the good, while consumers with willingness to pay $v_i > \bar{v}$ make use of the services provided by the exchange. The following proposition describes the consumers' participation decisions and bargaining behavior in the OTC market.

Proposition 5.1 *If at least one firm is active on the platform, then a fraction* $\bar{v} = \frac{p_e + b}{\alpha}$ *of consumers buy over-the-counter, where* p_e *is the minimum price posted on the trading platform. By Nash bargaining, the OTC buyers obtain a net utility of* $(1-\alpha)v_i$. *The remaining share of consumers,* $1-\bar{v}$, *obtains the good in the centralized marketplace and receives a net utility of* $v_i - p_e - b$. *If no seller enters the platform, all consumers trade in the OTC market.*

5.4.2 Firm platform participation and pricing strategies

Moving back one stage, firms decide whether to participate in the centralized marketplace or not and pick a price from the distribution function $F(p)$ to be posted at the platform. Participating in the platform can be profitable for a firm as it may happen that this firm posts the lowest price and, as a result, attracts all buyers who utilize the intermediation services. On the other hand, a firm that does not enter saves on the seller fee that has to be paid in order to become a member of the exchange. The equilibrium probability of firm entry in the platform is found by equalizing the expected profit from entry and the expected profit from bypassing the exchange.

Suppose first that firm j does not enter the platform; then its profit depends on whether any of its competitors does participate. With probability $\sum_{k=1}^{n-1}\binom{n-1}{k}\beta^k(1-\beta)^{n-1-k}$, at least one of the other firms decides to enter and firm j's profit in the decentralized market becomes

$$\pi_j^b = \frac{\alpha}{n}\int_0^{\bar{v}} v dv = \frac{(p_e+b)^2}{2\alpha n}. \tag{5.3}$$

Interestingly, if at least one seller is active at the platform, a firm's expected profit from selling over-the-counter increases both in the buyer fee and the (minimum) platform price. This already shows a trade-off for the firm: posting a very low platform price raises the probability of winning the price bidding game in the centralized marketplace, but decreases the profit from the OTC market. In case no firm participates in the exchange, which happens with probability $(1-\beta)^{n-1}$, all consumers have to turn to the OTC market and the profit of firm j becomes

$$\pi_j^b = \frac{\alpha}{n}\int_0^1 v dv = \frac{\alpha}{2n}. \tag{5.4}$$

Thus, the expected profit of firm j when it by-passes the exchange is given by

$$E\pi_j(NE) = (1-\beta)^{n-1}\frac{\alpha}{2n} + \sum_{k=1}^{n-1}\binom{n-1}{k}\beta^k(1-\beta)^{n-1-k}\frac{E[(p_e+b)^2]}{2\alpha n}, \tag{5.5}$$

where $p_e = \min\{p_{k\neq j}\}$ is the lowest price announced in the exchange if k competitors enter the exchange. Note that

$$E[(p_e+b)^2] = \int_{\underline{p}}^{\bar{p}} (x+b)^2 g(x)dx,$$

with

$$g(x) = kf(x)(1-F(x))^{k-1}.$$

Equation (5.5) can thus be rewritten as

$$E\pi_j(NE) = (1-\beta)^{n-1}\frac{\alpha}{2n} +$$
$$\frac{\beta}{2\alpha n}\int_{\underline{p}}^{\bar{p}}\sum_{k=1}^{n-1}\binom{n-1}{k}k(\beta(1-F(x)))^{k-1}(1-\beta)^{n-1-k}(x+b)^2 f(x)dx.$$

Applying the Binomial Theorem yields

$$E\pi_j(NE) = (1-\beta)^{n-1}\frac{\alpha}{2n} + \frac{\beta(n-1)}{2\alpha n}\int_{\underline{p}}^{\bar{p}}(x+b)^2 f(x)(1-\beta F(x))^{n-2}dx. \tag{5.6}$$

Suppose now instead that firm j decides to be active on the exchange and picks a price p; if k rivals also enter, then with probability $(1-F(p))^k$ seller j posts the lowest price and sells to a fraction $1-\bar{v} = 1 - \frac{p+b}{\alpha}$ of consumers in the centralized platform. Moreover, firm j obtains an additional profit from trading in the OTC market. With probability $1-(1-F(p))^k$, firm j does not set the lowest offer in the centralized marketplace and therefore only makes a profit in the bargaining market. The expected profit from entering the centralized marketplace thus equals

$$E\pi_j(E,p) = \sum_{k=0}^{n-1} \binom{n-1}{k} \beta^k (1-\beta)^{n-1-k} \times$$
$$\left[\left(p(1-\bar{v}(p)) + \frac{(p+b)^2}{2\alpha n} \right) (1-F(p))^k + \left(1-(1-F(p))^k\right) \frac{E\left[(p_e+b)^2 | p_e < p\right]}{2\alpha n} \right]$$
$$-s, \tag{5.7}$$

where $p_e = \min\{p_{k\neq j}\}$ is again the lowest price posted by the k rival firms that are active in the centralized marketplace. Equation (5.7) can be rewritten as follows:

$$\begin{aligned} E\pi_j(E,p) &= (1-\beta F(p))^{n-1} \left(p(1-\bar{v}(p)) + \frac{(p+b)^2}{2\alpha n} \right) \\ &+ \frac{\beta(n-1)}{2\alpha n} \int_{\underline{p}}^{p} (x+b)^2 f(x) (1-\beta F(x))^{n-2} dx - s. \end{aligned} \tag{5.8}$$

The first step to find the participation probability for firms is to note that in case a firm decides to enter any price from the range $[\underline{p}, \bar{p}]$ yields the same expected profit. To determine the expected payoff from entry, it is sufficient to obtain the profit (in expectation) for firm j if it sets the upper bound of the support of $F(p)$, $\bar{p}$:

$$\begin{aligned} E\pi_j(E,\bar{p}) &= (1-\beta)^{n-1} \left(\bar{p}\left(1 - \frac{\bar{p}+b}{\alpha}\right) + \frac{(\bar{p}+b)^2}{2\alpha n} \right) \\ &+ \frac{\beta(n-1)}{2\alpha n} \int_{\underline{p}}^{\bar{p}} (x+b)^2 f(x) (1-\beta F(x))^{n-2} dx - s. \end{aligned} \tag{5.9}$$

To derive the expression for $\bar{p}$, we first notice that a monopolistic seller in the centralized marketplace would charge a price

$$p_m = \frac{\alpha n - (n-1)b}{2n-1}.$$

In the remainder, we sometimes refer to this price as the *platform monopoly price*. Under the condition that $f(p) > 0$ for all $\underline{p} \leq p < p_m$ and $f(p) = 0$ for $p = p_m$,[22]

[22]Once we have derived the equilibrium distribution function, we will show that this condition holds at equilibrium.

it can easily be seen that (5.9) increases up to the platform monopoly price and decreases thereafter. We therefore get that the upper bound of the support of $F(p)$ is given by

$$\bar{p} = \frac{\alpha n - (n-1)b}{2n-1}.$$

Substituting this price into Equation (5.9) yields

$$\begin{aligned} E\pi_j(E,\bar{p}) &= (1-\beta)^{n-1}\frac{(\alpha^2+b^2)n - 2(n-1)\alpha b}{2(2n-1)\alpha} \\ &+ \frac{\beta(n-1)}{2\alpha n}\int_{\underline{p}}^{\bar{p}} (x+b)^2 f(x)(1-\beta F(x))^{n-2}dx - s. \end{aligned} \tag{5.10}$$

Since in equilibrium firms are indifferent between entering and not entering the exchange's platform, equalizing (5.6) and (5.10) gives the firm's probability of platform participation:[23]

$$\beta^* = 1 - \left(\frac{2n(2n-1)\alpha s}{((\alpha-b)n-\alpha)^2}\right)^{\frac{1}{n-1}}. \tag{5.11}$$

It can be seen from Equation (5.11) that the probability of firm entry in the centralized marketplace decreases in both the seller fee and the buyer fee. Obviously, if firms are charged a higher price for participation it becomes less beneficial for them to enter. Likewise, a rise in the fee for buyers lowers a firm's profitability of entering the platform as a smaller fraction of buyers will be found there. Furthermore, an increase in the sellers' bargaining power in the OTC market makes firm participation in the exchange more likely as sellers benefit from more buyers making use of the intermediation services.

To obtain the equilibrium price distribution $F^*(p)$, we now equate Equations (5.8) and (5.10). This yields the following expression:

$$\begin{aligned} &(1-\beta F(p))^{n-1}\left(p(1-\frac{p+b}{\alpha}) + \frac{(p+b)^2}{2\alpha n}\right) - (1-\beta)^{n-1}\frac{(\alpha^2+b^2)n-2(n-1)\alpha b}{2(2n-1)\alpha} \\ &-\frac{\beta(n-1)}{2\alpha n}\int_p^{\bar{p}}(x+b)^2 f(x)(1-\beta F(x))^{n-2}dx - s = 0. \end{aligned} \tag{5.12}$$

Differentiating (5.12) w.r.t. p and simplifying give

$$(1-\beta F(p))\left(1+\frac{p+b}{\alpha n} - \frac{2p+b}{\alpha}\right) - (n-1)\beta f(p)p\left(1-\frac{p+b}{\alpha}\right) = 0.$$

[23] Note that β^* lies in the interval $[0,1]$ as long as $s \in \left[0, \frac{((\alpha-b)n-\alpha)^2}{2n(2n-1)\alpha}\right]$. In the subgame perfect equilibrium, this condition will be satisfied.

Some algebra yields the equilibrium price condition:

$$F^*(p) = \frac{1}{\beta^*} - \frac{(1-\beta^*)}{\beta^*}\left(\left(\frac{(\alpha-b)n+b}{(2n-1)p}\right)^{1+\frac{b}{(\alpha-b)n}}\left(\frac{(\alpha-b)n-\alpha}{(2n-1)(\alpha-p-b)}\right)^{1-\frac{\alpha}{(\alpha-b)n}}\right)^{\frac{1}{n-1}}, \tag{5.13}$$

with support on $[\underline{p}, \bar{p}]$, where $\bar{p} = \dfrac{\alpha n-(n-1)b}{2n-1}$ and $\underline{p}$ solves $F(p) = 0$.

Clearly, when $\beta^* = 1$ this distribution function degenerates into a single mass point at $p = 0$. For $\beta^* < 1$, we still have to check whether $f^*(p) > 0$ for all $\underline{p} \leq p < p_m$ and $f^*(p) = 0$ for $p = p_m$, as we have assumed in order to obtain the expression for $\bar{p}$. Note that

$$f^*(p) = \frac{(\alpha-b)n+b-(2n-1)p}{(n-1)np(\alpha-b-p)}\frac{1-\beta^*F^*(p)}{\beta^*},$$

so we indeed obtain that $f^*(p) > 0$ for all $\underline{p} \leq p < p_m$ and $f^*(p) = 0$ for $p = p_m$. This also implies that $F^*(p)$ is continuous and increasing up to $\bar{p}$ ($= p_m$); this confirms that for $\beta^* < 1$, $F^*(p)$ is an atomless distribution (as has been implicitly assumed so far).[24]

To see how the equilibrium price distribution depends on the entry probability, let $F^*_{\beta_1}(p)$ be the price distribution when $\beta = \beta_1$ and $F^*_{\beta_2}(p)$ be the distribution when $\beta = \beta_2$. Then, $F^*_{\beta_1}(p)$ stochastically dominates $F^*_{\beta_2}(p)$ as long as $\beta_1 < \beta_2$ since

$$\frac{\partial F^*(p)}{\partial \beta} = \frac{\Omega - 1}{\beta^2} \geq 0 \;\; \forall \;\; p \in [\underline{p}, \bar{p}], \tag{5.14}$$

where

$$\Omega \equiv \left(\left(\frac{(\alpha-b)n+b}{(2n-1)p}\right)^{1+\frac{b}{(\alpha-b)n}}\left(\frac{(\alpha-b)n-\alpha}{(2n-1)(\alpha-p-b)}\right)^{1-\frac{\alpha}{(\alpha-b)n}}\right)^{\frac{1}{n-1}}.$$

This can also be seen in Figure 5.1, which displays the equilibrium price distributions for $\beta = 0.2$ and $\beta = 0.6$ (and $\alpha = 0.5$; $n = 3$; $b = 0.01$). Note that an increase in the probability of firm participation has a downward impact on the expected platform price. This also implies that a reduction in the seller fee, by increasing the entry probability, lowers the expected prices posted by the firms.

Unfortunately, for the other parameters (the buyer fee, the sellers' bargaining power and the number of active suppliers) we cannot analytically derive how they

[24]It is also easy to see that any price outside this support cannot be part of an equilibrium strategy. Suppose that firm j sets a price p lower than $\underline{p}$. It then certainly posts the lowest price and attracts all consumers who join the platform. Firm j however gains by raising its price to $\underline{p}$ because then it still undercuts its rivals with probability one but now charges a price closer to the platform monopoly price. Setting a price above $\bar{p}$ can never be profitable either, since by doing so firm j only sells in the centralized marketplace when no other firm decides to enter. Yet, we have seen that if firm j happens to be the only firm in the platform, the optimal price becomes $\bar{p}$.

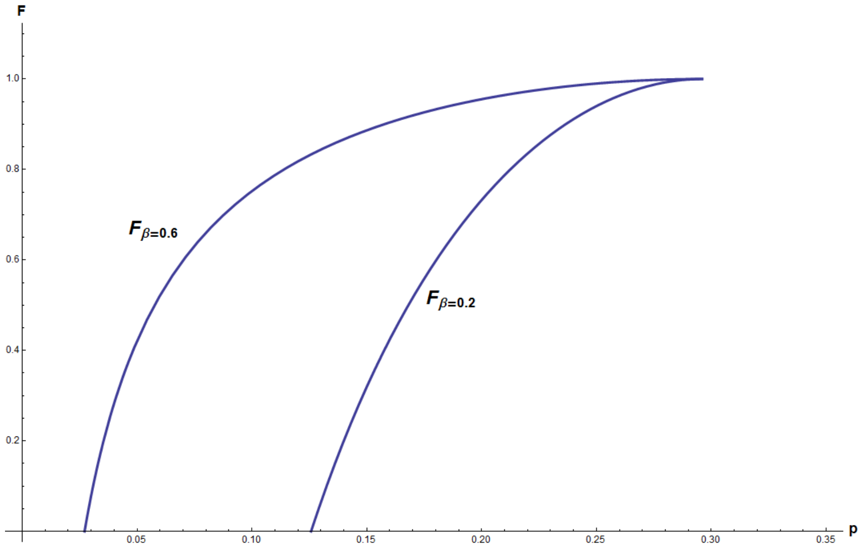

Figure 5.1: Equilibrium price distributions for $\beta = 0.2$ and $\beta = 0.6$ ($\alpha = 0.5$; $n = 3$; $b = 0.01$)

affect the equilibrium price distribution. To get some idea about this, we plot the price distribution for different values of b, α and n. Figure 5.3 displays how $F^*(p)$ is affected by changes in the participation charges for buyers.[25] We notice that increasing the buyer fee leads firms to post higher prices on average. This is due to the fact that a rise in the buyer fee lowers the probability of firm participation (see 5.11), which in turn has an upward impact on the prices posted on the platform (see 5.14). From Figure 5.4, we observe that a rise in the bargaining parameter increases the upper bound of the price distribution but at the same time decreases the lower bound. Finally, Figure 5.5 shows us that if there are more firms in the market the (expected) prices posted on the platform go down, although this impact is not very large.

The following proposition summarizes the optimal behavior of sellers.

Proposition 5.2 *Given the buyer and seller fees at the exchange, and anticipating consumer participation and OTC bargaining behavior, then in the symmetric equilibrium a firm j decides to be active in the OTC market with probability 1 while it chooses to post a price p in the centralized exchange with probability*

$$\beta^* = \min\left\{1, 1 - \left(\frac{2n(2n-1)\alpha s}{((\alpha - b)n - \alpha)^2}\right)^{\frac{1}{n-1}}\right\}.$$

[25] Figures 5.3, 5.4 and 5.5 are found in the Appendix.

If $\beta^* < 1$, the price p that is posted by firm j in the platform is randomly chosen from the distribution function that is given by Equation (5.13) with support on $[\underline{p}, \bar{p}]$, where $\bar{p} = \dfrac{\alpha n - (n-1)b}{2n-1}$ and $\underline{p}$ solves $F^*(p) = 0$. In case $\beta^* = 1$, the equilibrium distribution degenerates into a single mass point at $p = 0$.

5.4.3 Fee setting of the exchange

At the first stage, the exchange sets participation fees for buyers and sellers in order to maximize profit, taking into account the equilibrium strategies of both buyers and sellers in the continuation game. The expected profit of the exchange becomes

$$E\pi_e = \beta^*(b,s)ns + (1-(1-\beta^*(b,s))^n)\left(1 - \frac{Ep_e(b, \beta^*(b,s)) + b}{\alpha}\right)b, \qquad (5.15)$$

where $Ep_e(b, \beta^*(b,s)) \equiv \underline{p} + \int_{\underline{p}}^{\bar{p}} (1 - \beta^*(b,s)F(p)^*)^n \, dp - (1-\beta^*(b,s))^n \bar{p}$ is the expected minimum price posted in the exchange given that at least one firm decides to enter. This also implies that

$$1 - \frac{Ep_e(b, \beta^*(b,s)) + b}{\alpha},$$

is the expected fraction of consumers who enter the exchange. The expected profit for the platform owner consists of charging sellers for platform participation (the first term of Equation (5.15)) and setting a fee for consumers if they want to buy in the centralized marketplace (the second term of (5.15)). Note that with probability $(1-\beta^*(b,s))^n$, no firm enters the platform and no centralized trade is conducted.

Charging one side of the market

We start by looking at the optimal fee-setting behavior if only one side of the market can be charged. Suppose that sellers enter the centralized marketplace for free and that only buyers have to pay a participation fee. From Equation (5.11), we know that all firms will enter with probability one if entry is for free. This leads to a degenerate price distribution with a mass point at $p = 0$, which relates to the fact that with costless entry firms that compete in Bertrand fashion set price equal to marginal cost. Then Equation (5.15) simplifies to $\pi_e = (1 - b/\alpha)b$.[26] The following proposition describes the optimal buyer fee and corresponding profit for the exchange if only buyers have to pay for being active at the centralized marketplace.

[26] Note that in this case profits are deterministic, because all sellers enter the exchange and engage in marginal cost pricing with probability one.

Proposition 5.3 *Provided that only the buyer's side can be charged for platform participation, and anticipating the optimal buyer and seller behavior in the continuation game, a profit-maximizing exchange sets the participation fees equal to*

$$b^* = \alpha/2 \quad \textit{and} \quad s^* = 0.$$

These fees yield a profit of $\pi_e = \alpha/4$.

If instead only the sellers have to pay for being active at the centralized platform, the equilibrium probability of firm entry becomes

$$\beta^* = 1 - \left(\frac{2n(2n-1)s}{\alpha(n-1)^2}\right)^{\frac{1}{n-1}},$$

resulting in an expected profit for the intermediary that equals

$$E\pi_e = ns\left(1 - \left(\frac{2n(2n-1)s}{\alpha(n-1)^2}\right)^{\frac{1}{n-1}}\right). \tag{5.16}$$

Given Equation (5.16), we come to the following proposition.

Proposition 5.4 *Suppose that the exchange can only charge the seller's side for making use of the platform; then the optimal fees equal*

$$b^* = 0 \quad \textit{and} \quad s^* = \frac{\alpha(n-1)^2(1-1/n)^{n-1}}{2n(2n-1)}$$

and the probability of firm participation in the exchange becomes $\beta^* = 1/n$. *The intermediary's expected profit thus becomes* $E\pi_e = s^*$.

Comparing the exchange's profits under the two different regimes discussed above leads us to the following proposition.

Proposition 5.5 *For any* $n \geq 2$ *and* $\alpha \in (0,1)$ *the exchange owner is better off charging the buyer's side than letting sellers pay for participation.*

Proof The profit from letting buyers pay for platform participation is higher than the profit from only charging sellers if and only if

$$\frac{\alpha}{4} > \frac{\alpha(n-1)^2(1-1/n)^{n-1}}{2n(2n-1)}$$

or

$$\frac{1}{2} > \frac{(n-1)^{n+1}}{n^n(2n-1)}.$$

Note that for the right hand side, the following series of inequalities hold for any $n \geq 2$ and $\alpha \in (0,1)$:

$$\frac{(n-1)^{n+1}}{n^n(2n-1)} < \frac{n-1}{2n-1} < \frac{1}{2}$$

This already proves the proposition. ■

Costless entry for firms results in a competitive outcome on the trading platform, thus attracting a large share of consumers to the centralized marketplace. The exchange then extracts part of the surplus consumers reap from buying at the platform. In case buyers can enter for free, it again becomes attractive for a large set of consumers to utilize the services of the exchange. However, now the other side of the market does not benefit to the full extent, since an individual firm faces fiercer competition from rivals who compete for the big chunk of demand in the platform. The negative externality a firm imposes on its competitors by adhering to a more aggressive strategy decreases profitability on the (aggregate) seller's side and implies that the intermediary cannot extract much rent from firms.[27]

Charging both sides of the market

When the monopolistic exchange can charge both sides of the market, it has to take into account that the buyer's and seller's demand for making use of the intermediation services are interrelated. That is, a change in the participation fee for one side influences behavior on both sides of the market and, as a result, affects the exchange's profit obtained from buyers as well as from sellers. For instance, we have seen that an increase in the buyer fee leads to a fall in the participation rate of firms.

To see how changing the seller fee affects the intermediary's payoff from charging consumers, note from Equation (5.15) that the marginal profit of the intermediary from setting a seller fee equals

$$\begin{aligned}\frac{\partial E\pi_e}{\partial s} &= n\beta^* + ns\frac{\partial \beta^*}{\partial s} + \\ &\left(n(1-\beta^*)^{n-1}\left(1 - \frac{Ep_e + b}{\alpha}\right)b - \frac{(1-(1-\beta^*)^n)b}{\alpha}\frac{\partial Ep_e}{\partial \beta^*}\right)\frac{\partial \beta^*}{\partial s}. \quad (5.17)\end{aligned}$$

The last term of Equation (5.17) gives the marginal effect of s on the payoff from

[27] Negative intra-group externalities in two-sided settings are discussed in more detail by Belleflamme and Toulemonde (2009). They show that if intra-group externalities are neither weak enough nor strong enough, a for-profit platform cannot profitably enter a market where agents also have access to a free platform.

charging the buyer's side. Since

$$\frac{\partial E p_e}{\partial \beta^*} = -\frac{n}{1-\beta^*}(E p_e - \underline{p}) < 0 \quad \text{and} \quad \frac{\partial \beta^*}{\partial s} < 0, \tag{5.18}$$

this term becomes negative. This implies that an increase in the seller fee, though it may generate more revenue flowing from firms, leads to a loss in the payoff the platform owner receives from consumers. The reason for this is simple: a rise in s makes entry less profitable for firms, which reduces competitive pressures in the centralized marketplace and makes it also less attractive for buyers to enter.

Simulation results, reported in Figures 5.6, 5.7 and 5.8 in the Appendix, show that the negative inter-group effect from raising the seller fee is so strong that the exchange owner let firms enter for free.[28] As discussed before, costless entry for firms results in firms posting the competitive price which makes the platform an attractive marketplace for consumers to join. Since entry by sellers occurs with certainty, buyers benefit from full liquidity on the exchange. The intermediary, setting the buyer fee equal to $b^* = \alpha/2$, makes a profit by extracting part of the rents consumers obtain from buying in the centralized marketplace, thereby attracting half of the consumers to the platform. Interestingly, this result seems to depend neither on the number of suppliers nor on the firms' bargaining power in the OTC market. Note that sellers are worse off by the presence of a monopolistic intermediary. We already obtained that in case all trade is conducted over-the-counter, firm j's profit equals $E\pi_j = \dfrac{\alpha}{2n}$, while the firm's expected profit becomes $E\pi_j = \dfrac{\alpha}{8n}$ in case the intermediary is active in the market.[29] By contrast, consumers as a whole are better off when the exchange provides intermediation services. Note that in case of no intermediation, consumer's surplus equals $CS = (1-\alpha)\int_0^1 v dv = 1/2 - \alpha/2$, while if the exchange is active consumer's surplus becomes $CS = (1-\alpha)\int_0^{1/2} v dv + \int_{1/2}^1 (v - \alpha/2) dv = 1/2 - 3\alpha/8$.

5.5 Extension

In our basic model, we assume, in spirit of BM, that the firm chooses its entry decision and the price to post at the platform simultaneously. That is, at the time

[28] To find the participation fees that maximize the profit of the exchange, we can already rule out negative seller fees. Clearly, a profit-maximizing intermediary will never set a negative seller fee (which can be regarded as a subsidy for firms to enter). Suppose it did subsidize firms to enter the exchange; then all firms would take the subsidy by entering the centralized marketplace and end up charging a price equal to marginal cost. As we have seen before, the same price would prevail if firms participate in the trading platform for free which, in contrast to subsidizing firms, does not lead to a loss for the intermediary at the seller's side.

[29] Note that in the latter case, firms only make a profit in the decentralized market.

firms decide which price to set in the platform in case they enter, they do not observe the actions of other firms and therefore cannot condition their price on the entry (and pricing) decisions of their competitors. Therefore, by deciding to participate a firm affects the choice of consumers, and the ensuing seller's OTC profit, only through its own price (if it happens to be the lowest one posted) and not through the strategies of rival firms. The question that arises is whether the platform owner benefits from concealing information about entry decisions before firms have to pick a price to be posted at the exchange.

In this section, we consider the case where the platform owner makes public how many firms are active at the exchange before letting firms choose their pricing strategy. Thus, sellers who join the trading platform choose their exchange price after observing the entry decision of their rivals. We will see that this change in the timing of the model has major implications for firms' entry decisions and consequently, the profit for the exchange from providing intermediating services.

The last two stages of the game are the same as in the basic model. The indifferent consumer and firm's OTC profit are given by Equations (5.2), (5.3) and (5.4), respectively. However, firms that have entered the platform now pick a single price offer based on rivals' entry decisions in the previous stage. Suppose firm j has decided to enter; if firm j happens to be the only seller in the centralized marketplace, its aggregate (platform and OTC) profit equals

$$\pi_j = p(1-\bar{v}) + \frac{(p+b)^2}{2\alpha n}.$$

In this case, the optimal price for firm j is the monopoly platform price:

$$p_m = \frac{(\alpha-b)n+b}{2n-1}.$$

If at least one competitor also becomes active at the platform, Bertrand competition drives prices down to zero. Let k again be the number of firms that decide to utilize the intermediation services. If $k=0$, no price is posted and buyers have to go to the OTC market in order to buy the product; thus, the price in the platform becomes

$$p_e^* \quad = \quad \begin{cases} \frac{(\alpha-b)n+b}{2n-1} & \text{if } k=1 \\ 0 & k \geq 2 \end{cases} \tag{5.19}$$

Moving back one stage more, firms determine their entry strategy. When doing this, they take into consideration that their choice to enter may have considerable effects on the price that will prevail in the centralized marketplace. If, for instance, only one of firm j's competitors decides to participate, entry of firm j drives down the price to the competitive level; otherwise, the monopoly platform price will be charged. If seller j chooses not to enter, she saves on the participation fee but can only make a profit from selling over-the-counter. This OTC profit depends on the entry decision of her competitors. With probability $(1-\beta)^{n-1}$, none of firm j's competitors enter and no trade is conducted on the platform. This implies that all buyers are randomly matched to a seller in the OTC market, which yields a profit for firm j given by Equation (5.4). In case only one of j's competitors becomes active at the platform, which occurs with probability $(n-1)\beta(1-\beta)^{n-2}$, the monopoly price prevails in the centralized marketplace and firm j's profit is given by

$$\pi_j = \frac{(\alpha+b)^2 n}{2\alpha(2n-1)^2}.$$

In all other situations, firms sell at the competitive price and the profit of firm j becomes $\pi_j = b^2/2\alpha n$. Firm j's expected profit when it does not enter thus becomes

$$\begin{aligned} E\pi_j(NE) &= (1-\beta)^{n-1}\frac{\alpha}{2n} + (n-1)\beta(1-\beta)^{n-2}\frac{(\alpha+b)^2 n}{2\alpha(2n-1)^2} \\ &+ \big(1-(1-\beta)^{n-2}(1+(n-2)\beta)\big)\frac{b^2}{2\alpha n}. \end{aligned} \tag{5.20}$$

Consider now the case where firm j chooses to enter the platform. Then with probability $(1-\beta)^{n-1}$, firm j finds itself the sole seller in the centralized marketplace and the aggregate (platform and OTC) profit of j becomes

$$\pi_j = \frac{(\alpha-b)^2 n + 2\alpha b}{2\alpha(2n-1)} - s. \tag{5.21}$$

If, instead, at least one competitor also chooses to enter, the competitive price prevails on the trading platform and firm j only obtains revenues from selling over-the-counter. Since firm j still has to pay the seller fee, its aggregate profit equals

$$\pi_j = \frac{b^2}{2\alpha n} - s. \tag{5.22}$$

Summing (5.21) and (5.22) gives the expected total profit for firm j when it chooses to become active in the centralized marketplace:

$$E\pi_j(E) = (1-\beta)^{n-1}\frac{(\alpha-b)^2 n + 2\alpha b}{2\alpha(2n-1)} + \big(1-(1-\beta)^{n-1}\big)\frac{b^2}{2\alpha n} - s. \tag{5.23}$$

Equating (5.20) and (5.23) yields the equilibrium probability of firm participation in the platform. Unfortunately, for general n a explicit solution for β^* cannot be found. However, if $n=2$ we obtain a relatively simple expression for β^*:

$$\beta^*_{n=2} = \frac{3((\alpha-2b)^2 - 12\alpha s)}{7b^2 - 4\alpha b + 7\alpha^2}$$

or

$$\beta^*_{n=2} = 1 - \frac{4\alpha(\alpha + 2b + 9s) - 5b^2}{7b^2 - 4\alpha b + 7\alpha^2}. \tag{5.24}$$

Again, note that the equilibrium probability of entry decreases in the seller fee. How β^* changes in the buyer fee is somewhat less trivial.[30] The derivative of β^* with respect to b becomes

$$\frac{\partial \beta^*}{\partial b} = \frac{-18\alpha\Big((\alpha - 2b)(b + 4\alpha) + 4s(2\alpha - 7b)\Big)}{7b^2 - 4\alpha b + 7\alpha^2}.$$

Since the relevant region for b is $[-\alpha, \alpha/2)$, it can be seen from this derivative that the buyer fee reduces a seller's probability of platform participation.[31]

Next, it is interesting to see that even if sellers can join the platform for free, they will not always choose to enter. The reason for this is that a firm realizes that its decision to enter may lead to fierce competition in the centralized marketplace and, as a result, to a dramatic fall of the platform price. If the firm faces at least one rival, it will make no profit at all in the platform since firms then engage in marginal cost pricing. Moreover, the drop in the platform price has a negative impact on a firm's OTC profit, as more consumers buy in the centralized marketplace. Note that if the intermediary wants to induce full participation on the seller's side, is has to subsidize firm entry by an amount $s = -1/9\left(\alpha + 2b - \frac{5b^2}{4\alpha}\right)$. Given that participation fees are virtually always nonnegative, it means that under this setting buyers do not enjoy full liquidity at the exchange.

Finally, we look at the profitability of providing intermediation services for the case where $n = 2$. The expected profit for the intermediary is given by

$$E\pi_e = 2\beta^* s + \beta^{*2}(1 - b/\alpha)b + 2\beta^*(1 - \beta^*)\left(1 - \frac{2(\alpha + b)}{3\alpha}\right)b. \tag{5.25}$$

As before, the first term of Equation (5.25) gives the profit for the platform owner from charging sellers for becoming an exchange member. The second term is the intermediary's profit if both sellers enter, while the last term of (5.25) shows the profit for the exchange when only one of the firms decides to join the platform.

[30] For simplicity, we drop the subindex $n = 2$ from $\beta^*_{n=2}$ in what follows.

[31] To see why the exchange will never set a buyer fee that is lower than $-\alpha$, note that if only one firm posts a price the share of consumers that visit the exchange, $1 - \bar{v}$, becomes $1 - (2\alpha + 2b)/3\alpha$. If one then sets $b = -\alpha$, all buyers are attracted to the centralized marketplace. Of course, when two firms enter this negative fee again induces full participation at the buyer's side. It is also easily derived that charging consumers a fee higher than $\alpha/2$ is also suboptimal for the intermediary. We already know that $1 - \bar{v} = 1 - (2\alpha + 2b)/3\alpha$ when only one supplier is active at the exchange, which becomes zero when $b \geq 1/2$. When two sellers compete on the platform, the exchange attains the highest profit when $b = \alpha/2$.

Table 5.1 gives the optimal participation fees and the corresponding profit for the exchange for different values of α.

Finally, Figure 5.2 displays for different values of α the highest profit the intermediary can obtain when firms can condition their pricing strategies on the entry decision of their rivals (the solid line). From the figure, it can also been seen that this profit is always lower than the intermediary's profit in case sellers have to pick a price before they observe the degree of competition in the platform (illustrated by the dashed line). From this, we conclude that it is beneficial for an exchange not to reveal information about entry decisions before firms have posted their prices at the platform.

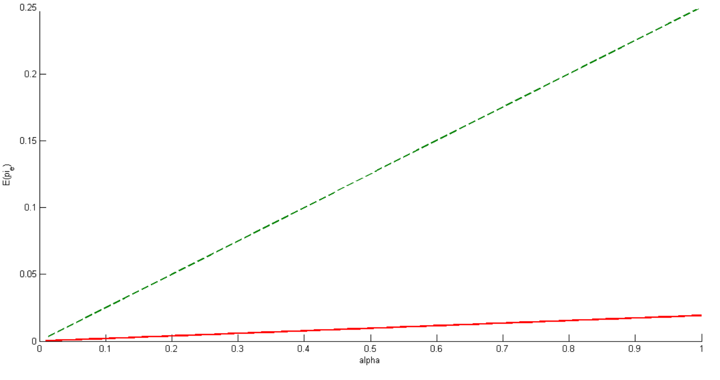

Figure 5.2: Comparison of the exchange owner's equilibrium profit

α	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.99
s	.0010	.0019	.0029	.0038	.0048	.0058	.0067	.0077	.0086	.0095
b	.0098	.0195	.0293	.0391	.0489	.0586	.0684	.0782	.0879	.0967
$E\pi_e$	.0019	.0038	.0058	.0077	.0096	.0115	.0134	.0153	.0173	.0190

Table 5.1: Profit-maximizing platform fees

5.6 Concluding remarks

In this chapter, we have shown that when buyers are heterogeneous in their willingness to pay, the introduction of a centralized exchange that operates a trading platform does not shift away all trade from the decentralized market. Low-valuation buyers benefit from a strong bargaining position in the OTC market and therefore do not find it profitable to pay for platform participation. By contrast, consumers with a high willingness to pay, suffering from being exploited to a large degree when negotiating with a seller, benefit from buying in the centralized marketplace. This is because on the platform, sellers can only post a single price thereby being unable to price discriminate across consumers. Moreover, sellers behave rather competitively in the centralized marketplace since the lowest-priced firm attracts all consumers who join the electronic platform.

In the context of energy wholesale markets, it seems reasonable to believe that the different types of buyers differ in their willingness to pay. For instance, in natural gas market retailers regard wholesale supply of gas as a necessary input as they resell essentially the same good to their costumers. Industrial consumers (e.g. electricity generators), on the other hand, can substitute away the use of natural gas in their input mix if gas becomes too expensive. In this light, it is interesting to notice that in the Dutch wholesale market for natural gas, retailers are the only type of buyers who are active at the centralized hub TTF. One possible explanation for the absence of industrial consumers in the TTF is that this buyer type benefits from the flexibility that OTC-traded contracts typically provide. However, another reason could be that these buyers have a relatively low willingness to pay.

By the participation fees it charges, the firm that operates the electronic platform plays an important role in shaping the market behavior of consumers and suppliers. Moreover, when deciding on its fees the exchange company has to take into account that buyers' and sellers' demand for the intermediation services of the exchange are interrelated. We find that the exchange maximizes profit by letting in firms for free, while charging consumers for joining the platform. In this way, it induces sellers to behave competitively which makes is attractive for a large group of buyers to join the centralized marketplace, even if they have to pay a participation fee. Quite remarkably, most real-world exchanges do not charge discriminatory fees to different trader types. Nevertheless, exchanges seem to consider the access fees as a key instrument for influencing the attractiveness of the electronic platform. APX-ENDEX, an electronic exchange that operates spot and futures markets for natural gas and electricity in the U.K., the Netherlands and Belgium, has reduced its fees various times in the last few years. As is stated in their website, the aim of this strategy is to create "higher market volumes (that) are translated into member benefits [...] (which) in turn is meant to boost the market liquidity further."

Not only the fee structure seems to be an important factor in determining the success of a centralized exchange. The institutional features of the trading platform, like the trading rules that are in place, could have an even bigger impact on the exchange's profitability. We show that the intermediary may gain from obliging sellers to make a price offer before they get to know the entry decisions of their competitors, since then firms tend to behave more competitively. This in turn makes the platform an attractive marketplace for consumers, which allows the exchange to extract more rents from the buyer's side.

5.A Appendix

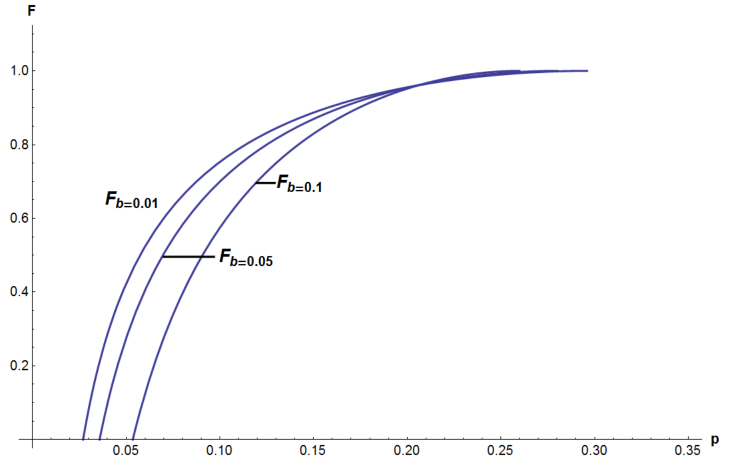

Figure 5.3: Equilibrium price distributions for $b = 0.01$, $b = 0.05$ and $b = 0.1$ ($\alpha = 0.5$; $n = 3$; $s = 0.01$)

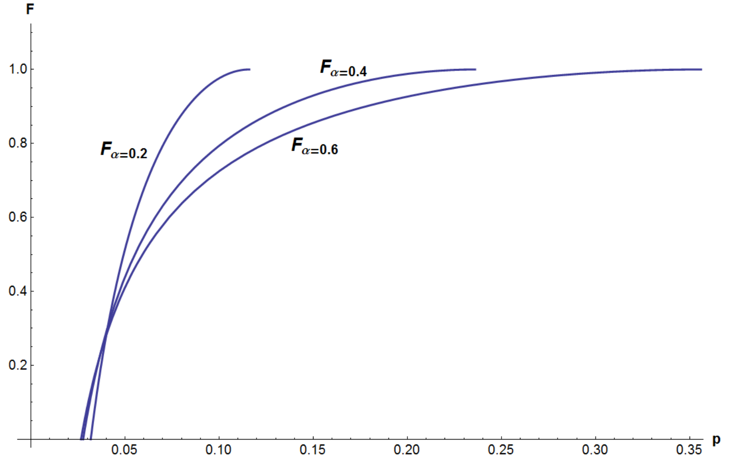

Figure 5.4: Equilibrium price distributions for $\alpha = 0.2$, $\alpha = 0.4$ and $\alpha = 0.6$ ($n = 3$; $b = 0.01$; $s = 0.01$)

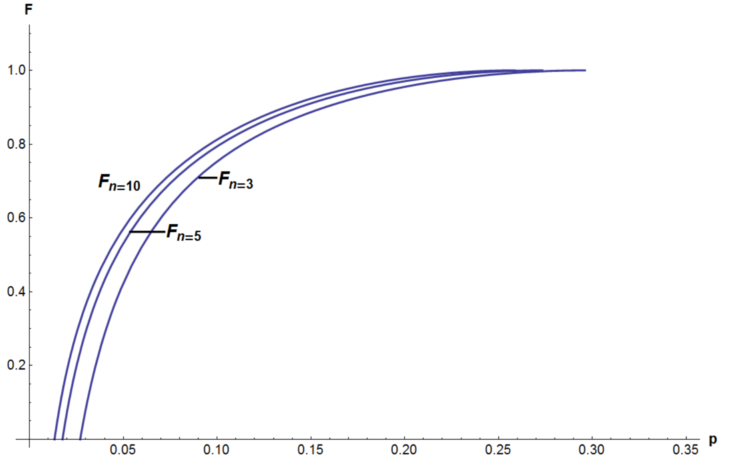

Figure 5.5: Equilibrium price distributions for $n = 3$, $n = 5$ and $n = 10$ ($\alpha = 0.5$; $b = 0.01$; $s = 0.01$)

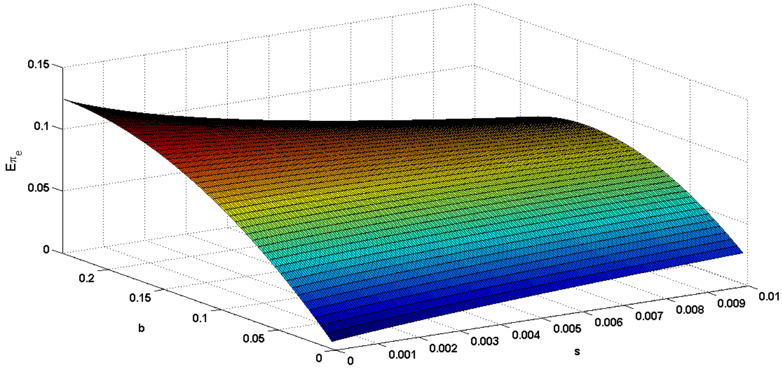

Figure 5.6: Exchange's profit when both sides of the market can be charged ($n = 5$, $\alpha = 0.5$)

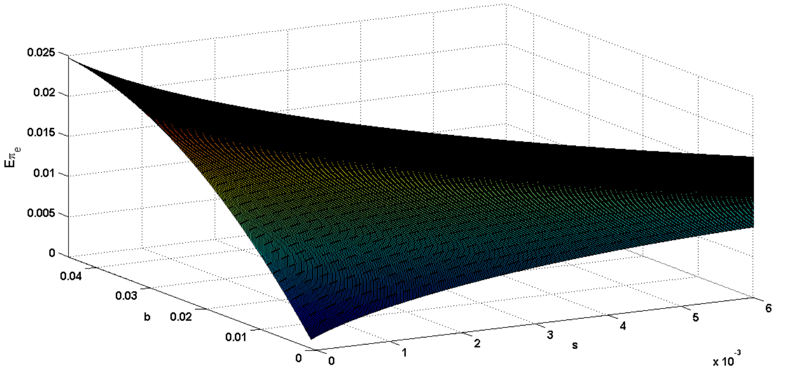

Figure 5.7: Exchange's profit when both sides of the market can be charged ($n = 10$, $\alpha = 0.1$)

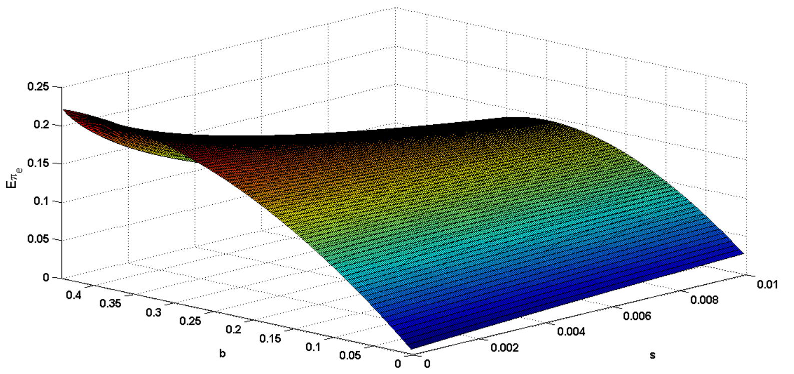

Figure 5.8: Exchange's profit when both sides of the market can be charged ($n = 3$, $\alpha = 0.9$)

Chapter 6

Conclusions

In the Introduction (Chapter 1), we have stressed the necessity of understanding how strategic interactions between market participants in deregulated energy industries shape market outcomes. In this final chapter, we summarize how the research documented in this thesis contributes to this notion. We also provide various policy recommendations and some suggestions for further research.

6.1 Thesis summary

In Chapter 2, we have looked at the extent to which access prices for gas pipelines affect competition on oligopolistic wholesale markets. The framework laid down in this chapter assumes two local markets connected by a pipeline that is owned by a regulated TSO. In each market, a single seller is located. The capacity of the physical network thus shapes the firms' incentives to deliver the good on each others' markets. We have shown that when the pipeline size is sufficiently large, neither firm has an incentive to congest the line. Focusing on the case in which the network operator has to recover its cost, the second-best tariffs for flow in both directions are positive and non-discriminatory as long as the two local markets are symmetric. Conversely, a relatively small network capacity creates an incentive for one of the suppliers to deliberately congest the line. In such a situation, transportation tariffs can be used to mitigate the welfare loss arising from congestion. To achieve this, the TSO has to subsidize the seller that is provoking congestion (the 'small' firm) in order to entice it to supply more. This alleviates congestion of the pipeline, thereby ensuring that not only the small firm exports more but also that the other firm can ship a higher output level to the distant market.

In contrast to Chapter 2, the focus in Chapter 3, 4 and 5 has been on trading institutions in restructured gas and electricity markets. In Chapter 3, we have developed an empirical strategy to test for the presence of strategic and/or risk-hedging reasons of selling forward. Due to deregulation policies, we have witnessed the emergence of markets for commodities where firms can sell both on a forward and on a spot basis. It is well-known that fixing the price (for part of the output) by trading forward not only allows firms to hedge against price volatility in the spot market, but also creates a competitive advantage over rival firms. The reason for this is that once firms have sold a share of their production against a fixed forward price, they attach a lower value to the spot price and are thus committed to a more aggressive spot strategy. As a result, competitors choose to adopt a compliant strategy in the spot market which has a positive effect on the contracting firm's profit. However, since all firms have an inventive to affect their rivals' spot strategies they all end up committing to a more competitive behavior by selling part of their output forward. As we have argued, the existence of this strategic incentive depends critically on whether forward positions become observed. In our theoretical model, we have parametrized the degree of market observability in order to separate the strategic motive from the risk-hedging reason. Our empirical strategy is based on the equilibrium restrictions that follow from the model. Crucial for identification of the two motives of selling forward is the variation in the number of active suppliers in the market.

In Chapter 4, this strategy has been applied to the Dutch wholesale market for natural gas. Using data on forward and spot sales, the number of wholesale suppliers and (variability in) prices at the the Dutch gas hub TTF, we have found that strategic considerations play a considerable role in firms' forward decisions. We believe this is an important result, given the fact that most of the TTF transactions are conducted over-the-counter. Though OTC markets are often thought to be relatively non-transparent, decentralized trade in the Dutch gas market seem to convey sufficient information content to permit wholesalers to trade forward for strategic reasons. By contrast, gas suppliers do not seem to sell forward to hedge against price risks in the spot market. In the chapter itself, one can read about possible explanations for why there is insufficient evidence that the risk-hedging motive is important when deciding on forward positions.

Finally, Chapter 5 has addressed the question whether OTC marketplaces can compete with organized exchanges, even in case the products transacted on both trading institutions are identical. This is a relevant research problem, since most of the existing work on this topic (Baye and Morgan, 2001; Galeotti and Moraga-González, 2009) establishes that all trade takes place at a centralized platform. In the chapter, we provide some evidence that this result seems at odds with trading patterns observed in real-world energy markets. We have shown that decentralized trade and B2B e-commerce can exist side by side when buyers differ in their willingness to pay. Purchasers with a high valuation for the good are willing to pay the participation fee charged by the exchange in order to be able to trade on the centralized platform. In this way, they avoid costly bargaining in the OTC market. Low-valuation buyers, on the contrary, bear a lower cost from one-to-one negotiations, which implies they prefer to transact in the decentralized market so as to save on the platform fee.

6.2 Policy implications

As has been recognized by the European Commission, the current state of energy markets is such that consumers still cannot reap the full benefits from the restructuring process. The main reason put forward by the EC is that suppliers on these markets maintain the ability to manipulate market outcomes. This thesis provides market designers with valuable insights about measures that could be implemented to improve the performance in energy industries.

First of all, this thesis delivers new insights about which access pricing scheme could be imposed by the regulator such that the welfare loss from oligopoly on downstream markets is minimized. In order to create a level playing field for entrants, legislators currently strive to ensure that every wholesaler has equal access to transport systems against the same prices. In places where the network owner is not fully unbundled yet, this attempt is praiseworthy as otherwise the non-affiliated suppliers run the risk of being foreclosed. While precluding the possibility to price discriminate on the basis of firm *identity* most likely benefits welfare, the results of Chapter 2 reveal that discriminatory tariffs based on firms' *incentives* can yield more efficient outcomes. For instance, access prices can be utilized to alleviate pipeline congestion, which at the moment is one of the major obstacles in creating well-functioning energy markets. If the regulator forbids the TSO to charge different tariffs for physical and reverse flow, a potential welfare gain is foregone.

Next, our empirical strategy in Chapter 3 provides scholars and policy makers with a way to test whether markets are sufficiently transparent so that forward contracts have commitment value for firms. In many countries, market designers have endeavored to increase market transparency by facilitating the opening of centralized spot and futures exchanges. However, it may sometimes be impossible to make a profit by operating an exchange, given that the associated cost can be substantial. For example, the Dutch energy futures exchange ENDEX had been confronted with losses in most years of its existence. In case public funds flow to a loss-making exchange in order to avoid bankruptcy, society bears the cost from operating a centralized marketplace at a loss. This can be validated only when the exchange conveys benefits to the public on other grounds. A potential advantage of futures markets is a relatively high level of transparency. The empirical method developed in Chapter 3 can be applied to see whether futures exchanges are indeed transparent enough to let suppliers sell forward for strategic purposes. Alternatively, the method can be used to test whether the information a particular decentralized market conveys to the participants is satisfactory. If this turns out to be true, the need to complement the OTC market with one or more organized exchanges becomes less urgent.

The allocation of public funds to exchanges may thus be a sound policy if the opening of a centralized marketplace leads to a substantial higher transparency in the market. In case exchanges are supported by the government, it is important to understand how these centralized marketplaces can operate at a profit as this could minimize the subsidy flowing to them. If the objective is to increase the exchange's revenues, legislators should for instance allow organized exchanges to set discriminatory participation fees for buyers and sellers. In particular, the results of Chapter 5 reveal that sellers should be charged a lower fee than buyers. Another way for the centralized marketplace to generate more revenue is to implement sound trading rules. We have established that if suppliers have to make a price offer before observing the entry decision of rival firms, they tend to price more competitively. This in turn attracts a higher share of buyers to the platform, which raises the exchange's profitability.

6.3 Directions for future research

We hope this thesis has given the reader a good understanding of the various incentives that are at play in energy markets and which type of policy measures could be implemented to bring these incentives more in line with the public interest. Still, by no means we claim that the research documented in this thesis addresses all the relevant issues concerning strategic interactions in the energy industry. In this light, it is useful to briefly discuss how our research could be extended and enriched to develop a more complete picture of the behavior of market participants.

A first natural extension pertains to Chapter 2, where we have looked at the optimal access pricing scheme in gas markets. Throughout this chapter, we have assumed that there is full information at the regulator's side about the cost structure of the network operator. In practice, and as we have mentioned in the Introduction, the regulator usually only has imperfect knowledge about the TSO's cost which further complicates finding the socially optimal transportation tariffs. By applying the *incentive regulation* theory, we could investigate how the optimal regulatory policy should be altered when there is asymmetric information. In particular, it would be interesting to see how the possibility of congested pipelines interplays with the information advantage of the TSO and whether the optimality of a discriminatory tariff system under congestion survives in this situation. Another intriguing problem to examine using this framework is how the TSO's incentives change if it is vertically integrated, i.e. if it owns one of the wholesale suppliers that use the network to reach their costumers. Research into this avenue will probably lead to valuable insights about how the regulated operator can be enticed to price discriminate on the basis of behavior rather than on firm identity, given the natural incentive of vertically integrated firms to foreclose non-affiliated downstream companies.

Our work on forward contracting also opens several avenues for further study. With respect to the theoretical framework developed in Chapter 3, we note that modelling (forward) market transparency as a single parameter is somewhat restrictive. A more realistic setting would consider a firm-specific probability of observing forward positions, permitting the econometrician to identify the observability parameter per firm. The main reason for why we have assumed that either all or none of the wholesalers become informed about forward sales is that our data set allows us only to estimate the commitment value of forward contracts at an industry level. Indeed, if in the future one is able to collect per-firm data on forward and spot sales for the TTF (or any other energy market that fits our theoretical model) the model has to be modified in order to identify the per-firm observability parameter. In addition, one could examine how the equilibrium results are changed when instead of risk neutrality, one assumes risk aversion at the buyer's side. In case perfectly competitive, risk-neutral arbitrageurs stand ready to buy and resell all of the forward contracts offered by suppliers, changing the buyers' risk preferences does not seem to affect the incentives of sellers. This presumably changes when there does not exist a fringe of competitive pure traders who arbitrage away differences between forward prices and (expected) spot prices (see e.g. Bessembinder and Lemmon, 2006).

Regarding our research on the competition between organized exchanges and OTC markets, we feel an interesting extension of the model is to consider a more sophisticated bargaining stage. For example, one could assume that buyers have the option to visit another seller in the decentralized market if they get an unacceptable offer. It is far from easy to envision how this modified assumption will alter the share of trade at each trading institution. On the one hand, the possibility to visit more than one supplier may make the decentralized market more attractive for buyers. On the other hand, sellers might post lower prices on the exchange to avoid ending up negotiating in the OTC market. This could potentially lure more consumers to the centralized marketplace. Another interesting issue to study in relation to the coexistence of the two trading institutions is the role of risk aversion. As we have noted in Chapter 5, the opportunity to transact tailor-made contracts over-the-counter may induce risk-averse traders to shun centralized exchanges where only highly standardized products change hands. An interesting question to address in this context is how a profit-maximizing exchange charges buyers and sellers for platform participation when both sides of the market differ in their degree of risk aversion.

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Samenvatting (Summary in Dutch)

Dit proefschrift gaat over verscheidene vormen van strategische interacties in energiemarkten, waarbij de nadruk sterk ligt op het gedrag van marktspelers in de (aard)gassector. Van oudsher was in vrijwel elk land ter wereld het aanbod van gas in handen van een verticaal geïntegreerde monopolist, die door de nationale overheid werd gereguleerd. Nederland was hierin geen uitzondering: tot het einde van de vorige eeuw was het de N.V. Nederlandse Gasunie die niet alleen het landelijke gastransportnet beheerde, maar ook verantwoordelijk was voor de levering aan eindgebruikers, zoals huishoudens en industriële afnemers. Het gas dat Gasunie distribueerde in het land was afkomstig uit de Nederlandse gasvelden of werd geïmporteerd vanuit het buitenland.

Het dereguleringsproces dat drie decennia geleden in de Angelsaksische energiesector zijn aanvang vond en zich langzamerhand heeft verspreid over de rest van de wereld, heeft geleid tot drastische veranderingen in de marktstructuur van de gasindustrie. Terwijl de transportinfrastructuur gewoonlijk nog in handen is gebleven van de gereguleerde monopolist, zijn de groothandels- en retailmarkten in veel landen opengesteld voor toetreding van nieuwe bedrijven.[1] Een hieraan gelateerd speerpunt van het hervormingsbeleid is de geleidelijke splitsing van de verticaal geïntegreerde monopolist, wat er op neerkomt dat men toe wil naar een situatie waarin het netwerkbedrijf niet meer zelf actief is in de handel van gas.[2] In Nederland is dit proces al voltooid: Gasunie is in 2005 opgesplitst in Gas Transportation Services (GTS) en GasTerra. GTS is verantwoordelijk voor het nationale transportnetwerk, terwijl

[1] De groothandelsmarkt is de markt waarop producenten en importeurs gas aanbieden aan industriële grootverbruikers en aan leveranciers van eindverbruikers. De retailmarkt is de markt waarop leveranciers van eindverbruikers leveren aan huishoudens en industriële kleinverbruikers.

[2] Een soortgelijk hervormingsproces is ook toegepast in de elektriciteitsmarkt.

GasTerra als handelsbedrijf actief is op de Europese groothandelsmarkt. Het doel van dit liberaliseringsproces is dat er meer concurrentie op de markt onstaat, wat uiteindelijk leidt tot een lagere energierekening voor zowel huishoudens als industriële afnemers.

Ondanks dat er verschillende beleidsmaatregelen zijn geïmplementeerd om marktwerking in zowel de gas- als elektriciteitsmarkt te bevorderen, bestaat er overtuigend empirisch bewijs dat bedrijven in deze markten in veel gevallen een substantiële invloed hebben op de prijs die tot stand komt. Ik laat in dit proefschrift zien dat deze marktspelers verschillende strategische instrumenten tot hun beschikking hebben om het spel van vraag en aanbod in hun voordeel te beïnvloeden. Men kan bijvoorbeeld denken aan het strategisch inkopen van netwerkcapaciteit, het wel of niet innemen van een positie in de termijnmarkt, of de keuze voor het handelen op centrale handelsbeurzen dan wel in *over-the-counter* (OTC) markten.[3] Het bestuderen van deze strategische variabelen en het effect ervan op marktuitkomsten is vanuit een maatschappelijk oogpunt buitengewoon relevant. Door een beter inzicht te krijgen in het gedrag van aanbieders kunnen beleidsmakers en toezichthouders maatregelen nemen die ervoor zorgen dat markten competitiever, en dus efficiënter, worden.

In Hoofdstukken 2 tot en met 5 van dit proefschrift bestudeer ik verschillende soorten strategische interacties die plaatsvinden op energiemarkten, waarbij ik me, zoals eerder aangegeven, vooral richt op de markt voor aardgas. Daarnaast kijk ik naar het effect van deze interacties op het functioneren van de markt en draag, waar mogelijk, beleidsmaatregelen aan die kunnen leiden tot een betere marktwerking. In wat volgt, zal per hoofdstuk worden uitgelegd wat de belangrijkste bevindingen zijn.

Bevindingen

Hoofdstuk 2

In Hoofdstuk 2 onderzoek ik het gedrag van groothandelsbedrijven in de gasindustrie omtrent het gebruik van het gastransportnet. Vanwege de schaalvoordelen die gemoeid zijn bij het beheren van het fysieke netwerk, is het transportnet vrijwel altijd in handen van één bedrijf dat wordt gereguleerd door een toezichthouder. De gebruikelijke naam voor zo'n netwerkbedrijf is *transmission system operator* (TSO). In ogenschouw nemend wat usance is in gasnetwerken, modelleer ik een situatie waar-

[3] Op de OTC markt vinden alle transacties plaats die min of meer tot stand komen na bilaterale onderhandelingen of door tussenkomst van een *broker*.

bij de TSO gebruik maakt van het *netting* principe. Dit wil zeggen dat contractuele stromen in tegengestelde richting tegen elkaar wegvallen, zodat de capaciteit van het transportnet beter benut wordt. Ik zal met een eenvoudig voorbeeld illustreren hoe *netting* in de gassector wordt toegepast. Veronderstel dat twee geografische gebieden, A en B, met elkaar zijn verbonden door een pijplijn met een capaciteit van 50 miljoen kubieke meter (= 50 mln. m^3) per dag. Daarnaast nemen we aan dat in elk geografisch gebied zich één gasaanbieder bevindt: bedrijf a in gebied A en bedrijf b in B. Zonder het bestaan van het transportnet zouden beide ondernemingen lokale monopolisten zijn; echter, de pijplijn stelt de bedrijven in staat om gas te leveren op elkaars markten. Als nu op een bepaalde dag in het jaar onderneming a 100 mln. m^3 aanbiedt op markt B en b 60 mln. m^3 wil leveren in A, dan zal de TSO, rekening houdend met het homogene karakter van gas, slechts 40 mln. m^3 hoeven te transporteren om aan de wensen van beide aanbieders te voldoen. Door gebruik te maken van *netting* treedt er in dit geval ook geen congestie op, daar de netwerkcapaciteit groter is dan de netto (contractuele) gasstroom.

In een vergelijkbare setting als hierboven beschreven, onderzoek ik de prikkel voor aanbieders om gebruik te maken van het fysieke netwerk dat beide markten met elkaar verbindt. Hoewel op het eerste gezicht het exporteren van een flinke hoeveelheid gas een winstgevende strategie lijkt te zijn, schuilt hier een addertje onder het gras.[4] Laten we eens de mogelijke strategieën van één van de aanbieders onder de loep nemen, zeg bedrijf a. Bedrijf a kan er voor kiezen om een substantieel marktaandeel te verkrijgen op de buitenlandse markt, waardoor het een relatief hoge omzet en winst behaalt in deze markt. Echter, door een grote hoeveelheid te exporteren, en gegeven dat de TSO gebruik maakt van *netting*, stelt a bedrijf b in staat om een aanzienlijk marktaandeel te verkrijgen in markt B, waardoor a lokale marktmacht verliest. Voor aanbieders bestaat er dus een afruil tussen het genereren van opbrengsten door het exporteren van gas en het koesteren van marktmacht in de lokale markt. In hoofdstuk 2 wordt aangetoond dat het voor een onderneming aantrekkelijker wordt om het exportniveau te verlagen naarmate de capaciteit van de pijplijn kleiner wordt, omdat er dan congestie optreedt en de andere aanbieder niet in staat is een grote hoeveelheid te transporteren.

De vraag die rijst is of een toezichthouder, zijnde de instantie die de TSO reguleert, instrumenten tot zijn beschikking heeft om gasexport attractiever te maken

[4] Voor redenen van leesbaarheid ga ik er in wat volgt van uit dat A en B twee verschillende landen zijn en gebruik ik de term 'exporteren' voor het leveren van gas door een bedrijf op de andere dan de lokale markt. De analyse geldt echter ook als de twee gebieden zich in één land bevinden.

en zodoende strategische congestie tegen te gaan. Ik laat zien hoe de transporttarieven die de TSO zet voor het gebruik van het netwerk gereguleerd dienen te worden om marktwerking te bevorderen. Ik richt me voornamelijk op de situatie waarin de TSO moet voldoen aan de gebruikelijke *break-even* voorwaarde.[5] Op beide markten zal de efficiëntie toenemen als de export van het bedrijf dat strategische congestie veroorzaakt, wordt gesubsidieerd. Deze aanbieder zal dan namelijk een sterkere prikkel hebben om te exporteren, wat congestie vermindert en uiteindelijk leidt tot een groter aanbod op beide markten. De middelen die nodig zijn om het ene bedrijf te subsidiëren worden opgehaald door een belasting te heffen op de export van de andere aanbieder. Het discriminatoire karakter van dit tariefsysteem is in strijd met de Europese regelgeving omtrent transporttarieven. Het beleid binnen Europa is er namelijk op gericht om een *level playing field* te creëren voor alle aanwezige marktspelers. Mijn onderzoek laat zien dat tariefdifferentiatie op basis van prikkels en daaruit voortvloeiend strategisch gedrag welvaartsverhogend kan zijn.

Hoofdstuk 3

In Hoofdstuk 3 van dit proefschrift staat de vraag centraal wat de motieven zijn voor spelers in een gedereguleerde markt om termijncontracten (ook wel: *forward* contracten) af te sluiten. In de context van energiemarkten kan een termijncontract gezien worden als een overeenkomst waarbij de verkoper verplicht wordt om in de toekomst een bepaalde hoeveelheid gas of elektriciteit te leveren aan de koper tegen een vooraf vastgestelde prijs. In energiemarkten lijken er twee hoofdmotieven voor *forward* handelen te bestaan. Ten eerste kunnen marktspelers een portfolio van termijncontracten beheren om prijsrisico's in de spotmarkt af te dekken, aangezien de termijnprijs wordt vastgelegd op het moment dat de overeenkomst wordt afgesloten.[6] Ten tweede kunnen bedrijven *forward* posities innemen voor strategische doeleinden. De strategische beweegreden is wat vernuftiger dan het risico-motief en vereist enige uitleg.

Veronderstel dat een energieleverancier zijn product kan aanbieden op zowel een *forward* markt als op een spotmarkt. Aangezien de handel in spotcontracten plaatsvindt nadat de termijnmarkt sluit, zal datgene wat er gebeurt op de termijnmarkt van invloed zijn op de spotmarkt. Hierdoor ontstaat er een prikkel voor de aanbieder om, door te handelen in *forward* contracten, het gedrag van concurrenten in de

[5] De *break-even* voorwaarde houdt in dat het reguleringsbeleid van de toezichthouder erop gericht is dat de gereguleerde onderneming niet wordt gesubsidieerd door de overheid.

[6] De spotmarkt is de markt waarin het afsluiten van het contract en de levering van het product op min of meer hetzelfde moment plaatsvinden.

spotmarkt in zijn voordeel te beïnvloeden. Het argument hiervoor luidt als volgt: wanneer een bedrijf een aanzienlijke hoeveelheid aanbiedt op de termijnmarkt, dan zal het relatief gezien weinig waarde hechten aan de hoogte van de prijs in de spotmarkt. Immers, een groot gedeelte van de productie is al verkocht tegen een vaste termijnprijs. Het bedrijf bindt zich op deze manier aan een agressieve strategie in de spotmarkt, waardoor het totale marktaanbod van deze aanbieder stijgt. Als de concurrenten dit gedrag in de *forward* markt observeren, zullen zij zich op hun beurt minder agressief gedragen in de spotmarkt om zodoende de spotprijs nog enigszins hoog te houden. Dit is natuurlijk gunstig voor de onderneming die een positie in de termijnmarkt inneemt.

Een relevante vraag in deze luidt of het bestaan van een termijnmarkt welvaartsverhogend is. Afgaande op de bestaande theorieën lijkt het gerechtvaardigd deze vraag bevestigend te beantwoorden. Ten eerste laat de economische literatuur zien dat de mogelijkheid tot het afdekken van risico's ertoe leidt dat een risico-averse onderneming meer zal aanbieden op de markt. Ten tweede zullen alle aanbieders een prikkel hebben om de spotstrategie van concurrerende bedrijven te beïnvloeden, wat leidt tot grotere posities in de *forward* markt en meer output en lagere prijzen in de markt als geheel. Echter, het strategische motief speelt alleen een rol als de handelingen van de spelers worden geobserveerd door de concurrenten, dus als de termijnmarkt voldoende transparant is. Derhalve is het zonder empirisch bewijs *a priori* niet evident dat de strategische beweegreden ook altijd in de praktijk aanwezig is.

Om die reden wordt in Hoofdstuk 3 een empirisch model ontwikkeld dat het mogelijk maakt om te toetsen of bedrijven termijncontracten verhandelen voor strategische doeleinden en/of het afdekken van prijsrisico's. Dit model maakt gebruik van variatie in het aantal actieve aanbieders en komt in het kort neer op het volgende. Stel dat de termijnmarkt volledig ondoorzichtig is, wat dus betekent dat het strategische motief voor het handelen in *forward* contracten niet bestaat. In dit geval zal een bedrijf enkel in de *forward* markt actief zijn om het risico van prijsfluctuaties in de spotmarkt af te dekken. Als nieuwe bedrijven toetreden op de markt daalt de residuele vraag voor een individueel bedrijf en daarmee ook de mate waarmee een bedrijf wordt blootgesteld aan prijsschommelingen in de spotmarkt. Dit heeft tot gevolg dat de prikkel om *forward* contracten te verkopen (*short* gaan) omwille van het afdekken van risico's kleiner wordt. Men kan in zo'n situatie dus een positief verband verwachten tussen het aantal actieve spelers in de markt en de verhouding totale marktaanbod/*forward* aanbod. Als de termijnmarkt wel voldoende transparant is, zal het *short* gaan van een marktspeler worden geobserveerd door zijn concurrenten. In deze situatie is het strategische motief van handelen in termijncontracten wel aanwezig en wordt het belangrijker naarmate er meer aanbieders actief zijn op de markt. Immers, door een *short* positie in te nemen in een transparante termijnmarkt beïnvloedt men de strategie van alle andere bedrijven op de markt. Een negatieve relatie tussen de verhouding totale marktaanbod/*forward* aanbod en het aantal actieve bedrijven duidt dus op een hoge mate van transparantie in de forward markt.

Hoofdstuk 4

In Hoofdstuk 4 wordt de methodologie die ontwikkeld is in Hoofdstuk 3 toegepast op de Nederlandse groothandelsmarkt voor aardgas. Voor dit empirische onderzoek maak ik gebruik van data van de Title Transfer Facility (TTF) voor de periode april 2003-juni 2008. De TTF is een virtuele handelsplaats waar marktpartijen (*shippers*) kunnen handelen in eigendomsrechten voor gas waarvoor transportcapaciteit al geboekt is. Deze *hub* is in 2003 in het leven geroepen om marktwerking in de Nederlandse gassector verder te bevorderen. Het bestaan van de TTF maakt het mogelijk om gas te kopen dat nog dezelfde dag op een bepaald *exit*punt wordt geleverd (spot gas), als ook te handelen in termijncontracten. Dit heeft geleid tot de toetreding van nieuwe spelers op de Nederlandse gasmarkt, waaronder een aantal buitenlandse groothandelsbedrijven als Gaz de France, EON en Statoil en financiële instellingen als JP Morgan, Morgan Stanley en BNP Paribas. Deze laatste groep toetreders is actief op de TTF voor speculatieve doeleinden. Het gevolg van de invoering van de TTF is dat handel in gascontracten niet langer enkel op *over-the-counter* (OTC) markten plaatsvindt, maar dat er tegenwoordig centrale handelsbeurzen bestaan waar gestandaardiseerde contracten verhandeld worden. APX Gas NL B.V. en ENDEX N.V. zijn de beurzen die zijn opgericht om respectievelijk spot- en termijnhandel op de TTF te faciliteren. Eind 2008 is ENDEX N.V. overgenomen door APX B.V., het moederbedrijf dat ook APX Gas NL B.V. bezit.

Gebruikmakend van gegevens over het aantal actieve groothandelsbedrijven dat actief is op de TTF in een bepaalde maand, heb ik het verband tussen het aantal actieve bedrijven en de verhouding totale marktaanbod/*forward* aanbod onderzocht. Als een standaard lineair regressiemodel wordt toegepast op de data, dan is de uitkomst dat er een negatieve relatie bestaat tussen het aantal actieve aanbieders op de TTF en de inverse hedge ratio in de markt. Deze uitkomst is een eerste indicatie dat de TTF-markt, die hoofdzakelijk bestaat uit OTC handel, voldoende transparant is om *shippers* de mogelijkheid te bieden termijncontracten te verhandelen voor strategische doeleinden. De uitkomsten van de lineaire regressie vertellen helaas niet in welke mate marktspelers te weten komen wat hun concurrenten hebben ondernomen in de termijnmarkt. Meer inzicht hierin kan verkregen worden door het model structureel te schatten. De resultaten van deze schattingsprocedure laten andermaal zien dat de termijnmarkt, en daarmee dus de OTC handel, relatief transparant is. Om precies te zijn: uit de schattingen komt naar voren dat bedrijven met 70-75 procent kans elkaars *forward* posities observeren. Deze uitkomst blijkt robuust te zijn als gecontroleerd wordt voor onder andere de prijsvolatiliteit in de spotmarkt en de endogeniteit van het aantal actieve marktpartijen. De conclusie dat de TTF als een relatief transparante handelsplaats gezien kan worden is opvallend, aangezien de meeste TTF-transacties *over-the-counter* plaatsvinden en OTC markten vaak als ondoorzichtig beschouwd worden.

Hoofdstuk 5

De vraag waarom spot- en termijncontracten zowel op centrale marktplaatsen als in OTC markten worden verhandeld, staat centraal in Hoofdstuk 5 van dit proefschrift. Als gevolg van de markthervormingen hebben we recentelijk de opkomst meegemaakt van handelsbeurzen waar gestandaardiseerde energiecontracten gekocht en verkocht kunnen worden. Deze centrale handelsplaatsen hebben in potentie een aantal gunstige eigenschappen voor marktpartijen, waaronder het bij elkaar brengen van beide kanten van de markt. Toch zien we nog altijd dat het merendeel van de contracten *over-the-counter* verhandeld wordt. Ik beargumenteer dat het naast elkaar bestaan van beide handelsplaatsen valt te verklaren door heterogeniteit aan de vraagkant van de markt. Hiermee wordt bedoeld dat potentiële kopers van elkaar verschillen met betrekking tot de reserveringsprijs.[7] Ik laat zien dat kopers met een hoge reserveringsprijs eerder bereid zullen zijn om te handelen op de centrale marktplaats dan in de OTC markt, terwijl voor vragers met een lage reserveringsprijs het omgekeerde geldt. De reden hiervoor is als volgt: daar waar de prijs in OTC markten veelal bepaald wordt door bilaterale onderhandelingen en dus positief gecorreleerd zal zijn met de reserveringsprijs van de koper, is de prijs die tot stand komt op de handelsbeurs, mede door de anonimiteit van de handelspartner, onafhankelijk van de identiteit van de koper. Dit heeft als gevolg dat vragers die een hoge waarde hechten aan het te verhandelen product een hogere prijs betalen in de OTC market dan kopers met een lage reserveringsprijs, terwijl de prijs op de beurs hetzelfde is voor

[7]Binnen de economische theorie gebruikt men gewoonlijk de term ‘reserveringsprijs’ voor de maximale prijs die een consument bereid is te betalen voor een product.

beide type kopers. Ergo: degenen met een hoge (lage) reserveringsprijs zullen veelal gebruik maken van de handelsbeurs (OTC markt). Deze segmentatie aan de vraagkant van de markt heeft ook gevolgen voor het gedrag van aanbieders. Naarmate er meer kopers actief op de handelsbeurs zijn, zal het voor verkopers ook steeds aantrekkelijker worden om toe te treden tot deze handelsplaats. Daarnaast hangt de kans dat een aanbieder actief wordt op de centrale handelsplaats in belangrijke mate af van de toegangsprijs die betaald moet worden om te kunnen verkopen op de beurs.

Het bedrijf dat het centrale platform beheert, zal bij het bepalen van de toegangsprijzen rekening moeten houden met het gedrag van spelers aan zowel de vraag- als aanbodkant. Een belangrijk resultaat dat wordt beschreven in Hoofdstuk 5 is dat de eigenaar van de handelsbeurs zijn winst optimaliseert als partijen aan de aanbodzijde geen toegangsprijs hoeven te betalen om toe te treden tot de beurs, terwijl spelers aan de vraagzijde dat wel moeten doen. Op deze manier wordt het aantrekkelijk voor verkopers om toe te treden, wat weer leidt tot meer concurrentie en lagere prijzen op het centrale handelsplatform. Hierdoor zullen kopers op hun beurt weer eerder geneigd zijn actief te worden op de beurs, wat de eigenaar van de centrale handelsplaats in staat stelt om een substantieel deel af te romen van het surplus dat kopers behalen door te handelen op de beurs.